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## RESEARCH MEMORANDUM

PRELIMINARY EVALUATION OF TURBINE PERFORMANCE WITH  
VARIABLE-AREA TURBINE NOZZLES IN A TURBOJET ENGINE

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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AREA TURBINE NOZZLES IN A TURBOJET ENGINE

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## SUMMARY

The performance of a two-stage turbine with variable-area first-stage turbine nozzles was determined in the NACA Lewis altitude wind tunnel over a range of simulated altitudes from 15,000 to 44,000 feet and engine speeds from 50 to 100 percent of rated speed. The variable-area turbine nozzles used in this investigation were primarily a test device for compressor research purposes and were not necessarily of optimum aerodynamic design. The results of this investigation are indicative of effects of turbine-nozzle-area variation on turbine performance within the operating range allowed by the engine. The variable-area turbine nozzles were found to be mechanically reliable and to have negligible leakage losses. Increasing the turbine-nozzle-throat area from 1.15 to 1.67 square feet increased the corrected turbine gas flow or effective turbine nozzle area about 10 percent. At a given corrected turbine speed and turbine pressure ratio, changing the turbine nozzle area from 1.30 to 1.67 square feet lowered the turbine efficiency 3 or 4 percent. The effect of increasing the turbine nozzle area from 1.15 to 1.67 square feet (decreasing the turning angle about  $7\frac{1}{2}^\circ$ ) would be to lower the turbine efficiency about 5 or 6 percent.

## INTRODUCTION

Analyses such as that given in reference 1 indicate the performance and operational advantages to be gained by utilization of variable-area turbine nozzles in turbojet engines. When combined with a proper speed control, the variable turbine nozzle can greatly increase the thrust capability of supersonic turbojet engines because of increased flexibility in matching of the compressor and turbine over a wide range of flight conditions. Furthermore, potential improvements in specific fuel consumption, particularly at thrust values below rated thrust, are possible for engines equipped with both variable-area turbine nozzles and variable-area exhaust nozzles (reference 1). In both these analyses, it was assumed that turbine efficiency was not affected by changes in the area or angle of the turbine nozzles. However, aside from analytical treatment of the problem, there exists at the present time a lack of

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experimental data on the performance of variable-area turbine nozzles operating as integral components of full-scale turbojet engines. Complexity and mechanical reliability have been the main deterrent factors in obtaining experimental data and in the utilization of variable turbine nozzles in present turbojet engine designs.

During a study of the surge characteristics of a turbojet engine fitted with variable-area first-stage turbine nozzles in the NACA Lewis altitude wind tunnel, it was possible to obtain some preliminary data on the effect of these nozzles on the performance of the two-stage turbine. The effect of the variable-area turbine nozzles on the efficiency and gas flow characteristics of the turbine are presented herein. The variable-area turbine nozzles investigated in this study were intended primarily to provide a variable compressor pressure ratio independent of engine speed and turbine-inlet temperature for compressor research purposes; therefore, the aerodynamic design of the nozzles was not necessarily optimum. Furthermore, the turbine rotors and the second-stage stator were designed for fixed-area first-stage nozzles. The experimental results obtained in this investigation, therefore, do not represent the best turbine performance obtainable with variable-area turbine nozzles, but serve instead as a preliminary indicator of general performance and mechanical problems.

Corrected turbine gas flow and turbine efficiency are presented as functions of corrected turbine speed and turbine pressure ratio to show the effects of turbine nozzle area and nozzle angle on turbine performance. The turbine efficiency obtained with the original fixed turbine nozzles is compared with the turbine efficiency obtained with the variable turbine nozzles at a position corresponding to approximately the same throat area and turning angle. All turbine performance data obtained with the variable turbine nozzles are presented in numerical form in table I.

## INSTALLATION AND INSTRUMENTATION

### Engine

The engine was mounted on a wing section which extended across the 20-foot-diameter test section of the altitude wind tunnel (fig. 1). Dry refrigerated air was supplied to the engine from the tunnel make-up air system through a duct connected to the engine inlet. Manually controlled butterfly valves in this duct were used to adjust the total pressure of the refrigerated air at the engine inlet to correspond to the desired flight condition, while the static pressure in the tunnel test section was maintained to correspond to the desired altitude. A slip joint with a frictionless seal in the duct permitted the measurement of thrust and installation drag with the tunnel scales.

The engine used in this investigation was a J40-WE-6, which had a sea-level rating of 7500 pounds of jet thrust at an engine speed of 7260 rpm and a turbine-inlet temperature of 1425° F. At this rating, the compressor pressure ratio was about 5.0 and the engine air flow was 140 pounds per second. A cross-section of the engine is presented in figure 2 showing the main components of the engine which included an eleven-stage axial-flow compressor, a single-annulus basket-type combustor, a two-stage turbine, and a clamshell-type variable-area exhaust nozzle. The engine was equipped with an electronic control that varied engine fuel flow and exhaust-nozzle area to maintain a schedule of turbine-outlet temperature and engine speed.

The original J40-WE-6 engine was modified before the investigation reported herein by replacing the compressor-outlet straightening-vane assembly with a two-element mixer-vane assembly, by using a slightly modified combustor basket, and by replacing the first-stage fixed turbine nozzles with a variable turbine-nozzle diaphragm. The original control was also modified to permit independent control of engine speed and exhaust-nozzle area.

#### Turbine

Both first- and second-stage turbine disks were solid steel and had an outer diameter of 21.90 inches. The first-stage rotor disk had 62 high-temperature-alloy blades fitted into its outer rim (fig. 3(a)) and the second stage contained 32 blades of the same material (fig. 3(b)). All turbine rotor blades were 5.50 inches in length; the turbine tip diameter was thus 32.90 inches and the hub-tip radius ratio was 0.666. The radial tip clearance for the turbine rotors was 5/32 inch.

The first-stage or variable turbine-nozzle diaphragm consisted of 56 high-temperature-alloy vanes which could be rotated between an inner and outer shroud (figs. 4(a) and 4(b)). All vanes were rotated simultaneously by an actuating mechanism similar to the one shown schematically in figure 5. The single actuating shaft extending through the engine outer skin was actuated by an externally mounted worm-gear drive. Changing the turbine-nozzle vane angle varied the nozzle throat area and also the angle that the fluid is turned in passing through the nozzles. Mid-vane cross sections of two adjacent turbine nozzle vanes are shown in the open and closed positions in figure 6. The solid-line section shows the vanes in the open position corresponding to a geometric throat area of 1.67 square feet and a turning angle at the throat of approximately 54.5°. The dashed-line section corresponds to the closed position with a throat area of 1.15 square feet and turning angle of about 62°. The original fixed turbine nozzles, for which the turbine rotors and second-stage nozzles were designed, corresponded closely to the variable turbine-nozzle setting that provided a throat area of 1.30 square feet and a turning angle of about 59°.

The second-stage or interstage stator consisted of 60 high-temperature-alloy vanes welded to an inner and outer shroud with a fixed nozzle-throat area of approximately 1.81 square feet. The annular passage through the turbine from first-stage nozzles to turbine outlet had approximately constant inner and outer diameters; the unblocked annular area was about 3.4 square feet.

### Instrumentation

Stations at which instrumentation was installed within the engine for measuring pressures and temperatures are shown in figure 2. The number of total and static pressure tubes, static pressure orifices, and thermocouples installed at each measuring station is shown in tabular form in this figure. Schematic sketches of the instrumentation at the cowl inlet (station 1), compressor outlet (station 4), turbine inlet (station 5), and turbine outlet (station 6) are shown in figure 7. Fuel flow was measured by calibrated rotameters and engine speed was measured by a stroboscopic tachometer.

### Procedure

Data were obtained at altitudes of 15,000, 30,000, 40,000, and 44,000 feet at various flight Mach numbers from 0.14 to 0.62. Extensive performance data were obtained at an altitude of 30,000 feet and a flight Mach number of 0.62. At this flight condition, the variable turbine nozzles were set at five different positions and at each nozzle position the engine was operated at six different speeds from 3630 to 7260 rpm (rated speed). At each turbine-nozzle setting and engine speed, the exhaust nozzle was varied from the wide-open position to full closed, or until limiting turbine temperature was approached, to extend the range of turbine pressure ratio and corrected turbine speed. The ranges of turbine pressure ratio, corrected turbine speed, turbine nozzle area, and engine speed covered at this flight condition are shown in the following table:

Engine speed, rpm . . . . .	3630 to 7260
Measured turbine-nozzle-throat area, sq ft . . . . .	1.15 to 1.67
Turbine pressure ratio . . . . .	1.57 to 3.00
Corrected turbine speed, rpm . . . . .	2663 to 4407

The symbols and methods of calculation used to determine the turbine performance are given in the appendix.

## RESULTS AND DISCUSSION

Inasmuch as the primary object is to show the effect of turbine nozzle area on turbine performance, curves are shown only for an altitude of 30,000 feet and a flight Mach number of 0.62 where the most extensive investigation was made. Data obtained at all of the flight conditions investigated are presented in numerical form in table I.

## Corrected Turbine Gas Flow

The variation of corrected turbine gas flow with corrected turbine speed for all five turbine nozzle areas is shown in figure 8 for an altitude of 30,000 feet and a flight Mach number of 0.62. Although turbine pressure ratio is not a direct function of corrected turbine speed, lines of constant turbine pressure ratio have been superimposed to indicate approximately the general increase in turbine pressure ratio with increased corrected turbine speed at each turbine nozzle area. For each of the five nozzle areas, the corrected gas flow increased with corrected turbine speed to a maximum value and was unaffected by further increases in corrected turbine speed or turbine pressure ratio. Failure of the corrected gas flow to increase at high corrected turbine speeds (and high turbine pressure ratios) is attributed to choking of the flow at some station within the turbine. The turbine pressure ratio for choking varied from about 2.6 at a turbine nozzle area of 1.15 square feet to about 2.2 at an area of 1.67 square feet. However, these values of turbine pressure ratio at the transition point between choked and unchoked flow are very approximate because of the data inaccuracy in the low range of turbine pressure ratios.

The maximum corrected turbine gas flow (choked conditions) obtained at each nozzle area is shown in figure 9. This curve is also a measure of effective turbine-nozzle throat area inasmuch as corrected turbine gas flow is directly proportional to effective area when the nozzles are choked. Over the range of actual turbine nozzle areas from 1.15 to 1.67 square feet, the effective turbine nozzle area varied from 1.13 to 1.25 square feet for an effective area range of approximately 10 percent. It is apparent that the effective and measured areas are nearly equal at small area settings of the nozzles but the effective area is considerably smaller than the measured area at large area settings. This indicates a reduction in nozzle flow coefficient (defined as the ratio of effective area to measured area) from about 0.98 to 0.75 as the nozzles are opened. This large reduction in indicated flow coefficient may be caused by choking at some station within the turbine other than the inlet nozzles. However, inasmuch as interstage pressures and temperatures were not measured, the location of the choking station within the turbine could not be determined with certainty.



### Turbine Efficiency

The turbine efficiencies obtained with all five turbine nozzle areas at an altitude of 30,000 feet and a flight Mach number of 0.62 are shown in figure 10 as a function of corrected turbine speed. The maximum turbine efficiency obtained was 0.87 with the smallest turbine nozzle area and a high corrected turbine speed. The minimum turbine efficiency was about 0.70 with the largest nozzle area and a low corrected turbine speed. In general, turbine efficiency increased with corrected turbine speed for all turbine nozzle areas and was lowered by increasing the turbine nozzle area (decreasing the nozzle turning angle) at a given corrected turbine speed. These general effects, however, are not clearly separated in figure 10 because the effects of turbine pressure ratio have not been accounted for.

In figures 11(a) and (b) to 15(a) and (b), operating lines of turbine pressure ratio and turbine efficiency are shown as functions of corrected turbine speed for each engine speed and turbine nozzle area. Although turbine efficiency is not a direct function of engine speed, lines of constant engine speed have been faired for the turbine efficiency data for the purpose of obtaining cross plots. The cross plots of turbine efficiency against corrected turbine speed for constant values of turbine pressure ratio obtained from parts (a) and (b) of figures 11 to 15 are shown in parts (c) of these figures. At a constant turbine pressure ratio, turbine efficiency increased with increased corrected turbine speed. This trend occurred at all values of constant turbine pressure ratio for which cross plots could be obtained at each turbine nozzle area. The maximum range of corrected turbine speed obtainable at a constant turbine pressure ratio was about 200 rpm and the average increase in turbine efficiency for this increase in corrected turbine speed was about 4 percent. However, the rate of increase in turbine efficiency with increased corrected turbine speed was greater at the lower values of constant turbine pressure ratio. At a given corrected turbine speed, turbine efficiency increased with reduced turbine pressure ratio, but the corrected turbine speed could be maintained constant only for a very small range of turbine pressure ratios.

The effect of changing turbine nozzle area and turning angle on turbine efficiency at a given corrected turbine speed and turbine pressure ratio is shown in figure 16. The symbols, which represent cross-plotted data points rather than actual data points, have been included to indicate the accuracy of the cross-plotted data as well as for distinguishing between turbine nozzle areas. In all cases where a comparison could be made at the same turbine pressure ratio and corrected turbine speed, the turbine efficiency was lowered by increasing the turbine nozzle area. Changing the turbine nozzle area from 1.30 to 1.67 square feet at constant values of corrected turbine speed and turbine pressure ratio

lowered the turbine efficiency by 3 or 4 percent. It is probable that the reduction in turbine efficiency over the complete range of turbine nozzle areas (decreasing the turning angle about  $7\frac{1}{2}^\circ$ ) would not be more than about 5 or 6 percent in the region of high corrected turbine speeds and turbine pressure ratios.

A comparison of turbine efficiencies obtained with the original fixed turbine nozzles and with the variable turbine nozzles at a corresponding area setting and at the same flight conditions and engine speed is shown in figure 17. The slightly lower turbine efficiency of about 1 percent (which is less than the data accuracy spread) obtained with the variable turbine nozzles indicates that the leakage losses with the variable nozzles were very small.

#### Mechanical Reliability

The variable-area turbine-nozzle diaphragm was installed in the engine during approximately 240 hours of engine operation and only minor mechanical difficulties were encountered during this period. Although the turbine nozzle area was not varied frequently during the part of the engine investigation reported herein, a great many changes in nozzle area were made during other parts of the investigation. The nozzles were at low physical loading conditions most of the time because most of the investigation was conducted at high altitudes, but inasmuch as a large part of the total operating time was at military speed and temperature, it is felt that these tests were a good indication of variable turbine nozzle life. Calibrations of turbine-nozzle-throat dimensions versus indicated nozzle setting showed good reproducibility of turbine nozzle areas.

#### CONCLUDING REMARKS

The variable-area turbine nozzles were found to be mechanically reliable and to have negligible leakage losses. It was possible to achieve a variation in corrected turbine gas flow or effective turbine nozzle area of about 10 percent by use of these variable turbine nozzles. At a given corrected turbine speed and turbine pressure ratio, changing the turbine nozzle area from 1.30 to 1.67 square feet lowered the turbine efficiency by 3 or 4 percent. The effect of increasing the turbine nozzle area from 1.15 to 1.67 square feet (decreasing the turning angle about  $7\frac{1}{2}^\circ$ ) would probably lower the turbine efficiency about 5 or 6 percent.

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## APPENDIX - CALCULATIONS

## Symbols

The following symbols are used in this report:

A	cross-sectional area, sq ft
g	acceleration due to gravity, 32.2 ft/sec <sup>2</sup>
H	enthalpy of air or gas mixture, Btu/lb
N	engine speed, rpm
P	total pressure, lb/sq ft absolute
p	static pressure, lb/sq ft absolute
R	gas constant, 53.4 ft-lb/lb-°R
T	total temperature, °R
T <sub>i</sub>	indicated temperature, °R
V	velocity, ft/sec
W <sub>a</sub>	air flow, lb/sec
W <sub>f</sub>	fuel flow, lb/hr
W <sub>g</sub>	gas flow, lb/sec
α	thermocouple impact recovery factor, 0.85
γ	ratio of specific heats for gases
δ	pressure correction factor, P/2116 (total pressure divided by NACA standard sea-level pressure)
η	adiabatic efficiency
θ	temperature correction factor, γT/(1.4)(519), (product of γ and total temperature divided by product of γ and temperature for air at NACA standard sea-level conditions)
ρ	density, slugs/cu ft

Corrected parameters:

$N/\sqrt{\theta_5}$	corrected turbine speed, rpm
$T_5/\theta_2$	corrected turbine-inlet temperature, °R
$\frac{W_g \sqrt{\theta_5}}{\delta_5 (\gamma_5/1.4)}$	corrected turbine-inlet gas flow, lb/sec
$\Delta H_t/\theta_5$	corrected turbine enthalpy drop, Btu/lb

Subscripts:

a	air
g	gas mixture
t	turbine
1	cowl inlet
2	compressor inlet
4	compressor outlet
5	turbine inlet
6	turbine outlet

#### Methods of Calculation

Total temperatures were calculated from thermocouple indicated temperatures with the equation

$$T = \frac{T_i \left( \frac{P}{P_i} \right)^{\frac{\gamma-1}{\gamma}}}{1 + \alpha \left[ \left( \frac{P}{P_i} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]} \quad (1)$$

Air flow. - Air flow was determined from pressure and temperature measurements at the cowl inlet (station 1) by use of the equation

$$W_{a,1} = \rho_1 A_1 V_1 = A_1 \sqrt{\frac{2g}{R}} \left( \frac{P_1}{\sqrt{T_1}} \right) \sqrt{\left( \frac{\gamma_1}{\gamma_1 - 1} \right) \left( \frac{P_1}{P_1} \right)^{\frac{\gamma_1 - 1}{\gamma_1}} \left[ \left( \frac{P_1}{P_1} \right)^{\frac{\gamma_1 - 1}{\gamma_1}} - 1 \right]} \quad (2)$$

Gas flow. - Gas flow was calculated from fuel-flow measurements and cowl-inlet air flow as follows:

$$W_g = W_{a,1} + W_f/3600 \quad (3)$$

Turbine-inlet temperature. - Turbine-inlet temperature was determined from the enthalpy and fuel-air ratio at the turbine inlet by use of temperature-enthalpy tables. Turbine-inlet enthalpy was calculated from the following equation which assumes that the turbine enthalpy drop equals the compressor enthalpy rise:

$$H_{g,5} = H_{g,6} + \frac{W_{a,1}}{W_g} (H_{a,4} - H_{a,2}) \quad (4)$$

Turbine efficiency. - The turbine adiabatic efficiency was determined from the following equation:

$$\eta_t = \frac{1 - \frac{T_6}{T_5}}{1 - \left( \frac{P_6}{P_5} \right)^{\frac{\gamma_t - 1}{\gamma_t}}} \quad (5)$$

where  $\gamma_t$  is the average value of  $\gamma$  between stations 5 and 6.

## REFERENCES

1. Silvern, David H., and Slivka, William R.: Analytical Investigation of Turbines with Adjustable Stator Blades and Effect of These Turbines on Jet-Engine Performance. NACA RM E50E05, 1950.

TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE



Run	Altitude (ft)	$M_0$	$P_0$ (lb sq ft)	Turbine nozzle area (sq ft)	$N$ (rpm)	$W_r$ (lb hr)	$P_2$ (lb sq ft)	$T_2$ (°R)	$T_4$ (°R)	$P_5$ (lb sq ft)	$T_5$ (°R)	$P_6$ (lb sq ft)	$T_6$ (°R)	$W_{a,1}$ (lb sec)	$W_{a,5}$ (lb sec)	$\eta_t$	$P_5/P_6$	$N$ (rpm)	$\Delta H_t$ $\frac{\sqrt{g}}{g}$ (ft)	$T_5$ $\frac{\sqrt{g}}{g}$ (°R)	$W_{a,5}\sqrt{g}$ $\frac{W_{a,5}}{g}$ (lb sec)	$W_{a,1}(3500)$	$T_5$ $T_6$	
1	15,000	0.424	1185	1.15	7280	3140	1540	499	856				1191											
2		.464	1189	1.15	7280	3525	1379	495	858	6421	1563	2210	1259	96.40	96.38	0.8637	2.905	4281	30.2	1840	56.36	0.0103	1.262	
3		.484	1189	1.15	7280	3953	1379	494	866	6626	1680	2370	1325	96.48	96.58	.8773	2.795	4163	29.7	1745	56.53	.0115	1.253	
4		.480	1198	1.15	7260	4540	1592	494	871	6784	1720	2479	1582	96.72	96.93	.8753	2.740	4095	29.2	1808	56.42	.0128	1.245	
5		.467	1188	1.15	7260	4795	1379	494	880	6964	1850	2669	1503	96.48	96.79	.8849	2.619	3956	27.9	1844	57.18	.0140	1.231	
6		.459	1199	1.18	6897	2855	1385	495	824	5979	1410	2016	1116	93.25	94.02	.8407	2.965	4286	30.4	1479	55.88	.0085	1.263	
7		.455	1181	1.15	6897	3515	1372	491	837	6240	1560	2264	1251	92.67	93.65	.8613	2.788	4071	28.9	1649	56.34	.0105	1.247	
8		.457	1200	1.15	6897	3785	1384	490	839	6584	1600	2378	1294	93.54	94.59	.8540	2.686	4022	28.2	1694	56.38	.0112	1.236	
9		.453	1185	1.15	6897	4195	1375	490	849	6531	1704	2547	1386	92.98	94.15	.8601	2.584	3905	27.6	1805	56.76	.0126	1.229	
10		.460	1198	1.15	6897	4610	1385	496	862	6710	1810	2689	1486	93.04	94.32	.8751	2.514	3800	26.7	1895	57.13	.0138	1.218	
11		.484	1188	1.15	6353	2255	1377	492	781	5216	1300	1822	1058	84.84	85.46	.8289	2.863	4080	28.5	1372	55.75	.0073	1.255	
12		.456	1191	1.16	6353	2590	1374	491	789	5357	1394	1968	1128	84.11	84.83	.8259	2.722	3951	27.5	1473	55.96	.0084	1.238	
13		.456	1192	1.15	6353	3000	1375	491	801	5482	1485	2070	1213	83.50	84.33	.8292	2.638	3838	27.0	1570	56.43	.0100	1.224	
14		.467	1186	1.15	6353	3250	1377	490	802	5621	1555	2255	1280	82.72	83.62	.8383	2.514	3757	25.9	1647	55.75	.0109	1.215	
15		.467	1197	1.18	6353	3815	1381	491	809	5739	1660	2359	1369	81.88	82.88	.8430	2.432	3651	25.1	1744	56.86	.0125	1.205	
16		.469	1183	1.15	5908	1900	1375	488	676	4564	1150	1869	966	73.75	74.25	.8988	2.615	3851	21.6	1225	54.25	.0068	1.190	
17		.471	1184	1.15	5908	2115	1381	487	758	4492	1310	1742	1082	73.40	73.99	.7896	2.575	3718	20.0	1395	56.42	.0080	1.211	
18		.472	1178	1.15	5908	2455	1370	486	743	4546	1420	1891	1191	70.28	70.98	.7895	2.404	3583	23.6	1515	55.75	.0097	1.192	
19		.460	1186	1.15	5908	2795	1371	480	748	4631	1550	2029	1290	66.99	67.77	.8215	2.282	3459	23.1	1655	53.55	.0118	1.186	
20		.455	1188	1.15	5908	3015	1369	486	785	4586	1650	2142	1388	68.71	69.55	.8540	2.141	3359	22.1	1736	56.28	.0122	1.176	
21		.475	1176	1.15	4719	1095	1372	489	850	2669	1050	1514	896	52.10	52.40	.7534	2.183	3352	19.7	1114	55.51	.0058	1.169	
22		.486	1182	1.15	4719	1229	1388	486	851	2982	1096	1420	958	52.17	52.51	.7865	2.100	3286	19.4	1168	54.78	.0065	1.167	
23		.462	1185	1.15	4719	1365	1371	487	857	3006	1165	1500	1006	50.80	51.18	.8053	2.003	3193	18.7	1241	54.72	.0075	1.159	
24		.472	1182	1.15	4719	1511	1377	487	863	3100	1230	1602	1085	49.70	50.12	.8424	1.935	3111	18.7	1310	53.47	.0084	1.157	
25		.474	1186	1.15	4718	1639	1383	488	888	3146	1390	1828	1124	49.19	49.65	.8699	1.932	3045	18.3	1374	53.51	.0093	1.148	
26		.467	1180	1.15	3630	785	1370	485	580	2032	940	1217	850	56.81	57.03	.7258	1.670	2717	12.3	1005	52.31	.0059	1.106	
27		.472	1177	1.15	3630	879	1371	485	584	2069	990	1285	902	58.17	56.41	.7234	1.613	2652	12.3	1068	51.91	.0068	1.098	
28		.482	1192	1.18	3630	965	1387	485	588	2163	1055	1394	981	58.20	56.47	.7795	1.563	2574	12.1	1128	51.42	.0074	1.088	
29		.460	1193	1.30	7280	3570	1378	483	812	5924	1490	2124	1190	98.98	97.80	.8394	2.769	4392	28.9	1591	60.30	.0097	1.244	
30		.463	1183	1.30	7280	3785	1369	493	836	---	---	---	1289	95.29	96.34	---	---	4243	28.0	1677	---	.0110	1.236	
31		.459	1192	1.30	7280	4495	1377	489	844	6339	1743	2458	1430	98.18	97.43	.8782	2.486	4070	28.7	1849	61.02	.0130	1.219	
32		.464	1187	1.30	6897	3006	1378	495	803	5533	1430	2027	1153	92.54	93.37	.8364	2.739	4339	28.0	1800	60.21	.0080	1.240	
33		.483	1187	1.30	6897	3485	1374	485	815	5787	1641	2238	1259	92.42	93.39	.8477	2.576	4098	27.2	1815	60.39	.0106	1.234	
34		.482	1190	1.30	6897	3855	1377	494	825	5935	1827	2378	1332	92.75	93.80	.8718	2.501	3991	26.5	1710	60.84	.0115	1.221	
35		.463	1184	1.30	6897	4450	1371	496	831	6130	1748	2582	1448	92.11	92.85	.8803	2.592	3980	26.4	1830	60.74	.0134	1.209	
36		.464	1186	1.30	6353	2400	1375	493	784	4923	1327	1855	1085	86.00	86.87	.8080	2.653	4041	25.9	1397	60.59	.0078	1.225	
37		.484	1185	1.30	6353	2690	1374	492	776	5115	1433	2051	1180	85.39	86.19	.8318	2.493	3900	26.8	1312	60.44	.0094	1.214	
38		.462	1188	1.30	6353	3390	1374	491	785	5316	1583	2256	1301	84.45	85.39	.8490	2.356	3746	24.7	1852	60.37	.0112	1.201	
39		.463	1189	1.30	6353	3685	1375	490	794	5501	1680	2425	1412	83.61	84.89	.8548	2.288	3622	23.7	1779	60.14	.0129	1.190	
40		.490	1188	1.30	6353	4380	1374	489	799	5816	1800	2675	1531	82.61	83.85	.8494	2.182	3510	22.8	1910	60.50	.0148	1.176	
41		.464	1188	1.30	5808	1685	1374	491	724	4144	1230	1865	1007	75.77	76.29	.8563	2.488	3829	24.7	1300	60.88	.0068	1.221	
42		.464	1187	1.30	5808	2230	1376	487	727	4310	1323	1823	1103	75.17	75.79	.8180	2.384	3702	23.5	1409	60.41	.0082	1.199	
43		.483	1185	1.30	5808	2500	1372	486	733	4381	1410	1933	1194	73.35	74.22	.8004	2.256	3594	22.6	1502	60.48	.0094	1.181	
44		.457	1184	1.30	5808	2890	1374	488	743	4477	1540	2073	1310	72.34	73.14	.8332	2.159	3449	21.9	1640	60.81	.0111	1.178	
45		.459	1186	1.30	5808	3295	1372	487	753	4570	1673	2195	1437	70.28	71.20	.8384	2.082	3319	20.9	1782	60.75	.0130	1.164	
46		.464	1187	1.30	4719	1178	1375	486	644	2788	1083	1410	933	58.38	52.71	.8123	1.984	3302	18.6	1158	58.25	.0082	1.161	
47		.467	1185	1.30	4719	1295	1375	483	645	---	---	---	988	52.33	52.89	---	---	3215	18.1	1253	---	.0088	1.161	
48		.471	1184	1.30	4719	1530	1378	481	646	2841	1243	1676	1080	52.08	52.43	.8583	1.885	3096	17.8	1342	59.33	.0089	1.151	
49		.464	1188	1.30	4719	1655	1374	482	653	3004	1293	1830	1137	51.21	51.87	.8112	1.842	3041	17.4	1393	58.39	.0080	1.137	
50		.468	1184	1.30	4719	1740	1374	480	653	---	---	---	1168	51.32	51.80	---	---	3000	17.4	1439	---	.0094	1.138	
51		.470	1183	1.30	3630	814	1375	484	573	1987	955	1282	868	37.71	37.84	.8178	1.534	2699	12.2	1023	55.81	.0060	1.100	
52		.467	1185	1.30	3630	1022	1376	483	582	2086	1108	1192	1009	36.56	36.84	.8386	1.750	2514	11.5	1181	54.87	.0078	1.098	
53		.463	1190	1.67	7260	5940	1378	485	813	5787	1873	---	1279	98.88	97.43	---	---	4288	27.3	1882	63.35	.0111	1.250	
54		.480	1180	1.67	7260	4040	1384	491	827	5820	1643	---	1348	84.20	93.32	---	---	4182	26.5	1715	63.20	.0119	1.219	
55		.465	1186	1.67	7260	4310	1373	491	824	5956	1690	1920	1384	95.40	98.60	---	---	4138	28.0	1778	63.37	.0125	1.214	
56		.457	1183	1.67	7260	4720	1365	493	837	6090</														

TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Continued



Run	Altitude (ft)	M <sub>0</sub>	P <sub>0</sub> (lb /sq ft)	Turbine nozzle area (sq ft)	N (rpm)	W <sub>r</sub> (lb /hr)	P <sub>2</sub> (lb /sq ft)	T <sub>2</sub> (°R)	T <sub>4</sub> (°R)	P <sub>5</sub> (lb /sq ft)	T <sub>5</sub> (°R)	P <sub>6</sub> (lb /sq ft)	T <sub>6</sub> (°R)	W <sub>a,1</sub> (lb /sec)	W <sub>s,5</sub> (lb /sec)	η <sub>t</sub>	P <sub>5</sub> /P <sub>6</sub>	N √B <sub>5</sub> (rpm)	ΔH <sub>t</sub> B <sub>5</sub> (Btu /lb)	T <sub>5</sub> B <sub>5</sub> (°R)	W <sub>r,5</sub> √B <sub>5</sub> B <sub>5</sub> (lb /sec)	W <sub>r</sub> W <sub>a,1</sub> (3600)	T <sub>5</sub> T <sub>6</sub>
57	15,000	0.453	1188	1.87	7260	5030	1388	487	830	8210	1830	2307	1525	85.40	96.80	0.7881	2.892	3978	24.8	1949	63.72	0.0146	1.200
58		.455	1183	1.87	8897	5370	1362	504	807	8374	1507	-----	1255	80.85	91.79	-----	-----	4135	25.3	1552	62.92	.0103	1.220
59		.460	1186	1.87	8897	5785	1371	497	805	8571	1580	1951	1302	92.05	93.10	.7473	2.835	4048	25.8	1650	63.14	.0114	1.214
60		.464	1186	1.87	8897	6053	1378	500	815	8677	1630	2125	1370	91.99	93.12	.7696	2.874	3984	25.1	1715	63.45	.0123	1.204
61		.467	1186	1.87	8897	6480	1377	496	817	8878	1730	2205	1448	92.48	93.72	.7487	2.883	3881	24.4	1811	63.24	.0135	1.185
62		.460	1181	1.87	8897	6890	1365	499	827	8993	1826	2361	1538	91.45	92.81	.7888	2.838	3785	25.6	1898	63.21	.0148	1.188
63		.464	1184	1.87	8353	2695	1374	496	762	4766	1370	1853	1138	85.45	86.18	.7729	2.883	3983	24.8	1425	63.03	.0088	1.208
64		.464	1191	1.87	8353	3160	1361	497	769	8018	1473	2024	1250	85.33	86.21	.7888	2.478	3850	24.5	1538	62.51	.0103	1.198
65		.457	1183	1.87	8353	3646	1365	496	777	5134	1600	2190	1349	84.49	85.60	.8054	2.344	3707	22.8	1675	63.34	.0130	1.166
66		.459	1186	1.87	8353	4075	1370	496	789	5313	1703	2377	1442	85.50	84.63	.8377	2.235	3601	22.8	1785	62.89	.0136	1.181
67		.462	1187	1.87	8353	4450	1374	496	792	5428	1785	2486	1537	82.84	84.08	.8123	2.463	3516	21.5	1868	62.88	.0149	1.167
68		.462	1181	1.87	5608	2090	1366	473	874	4092	1215	1690	1023	77.08	77.66	.7488	2.421	3654	21.8	1332	62.38	.0075	1.188
69		.462	1182	1.87	5608	2500	1366	487	722	4204	1377	1808	1168	75.38	76.07	.7660	2.326	3632	21.8	1447	63.33	.0092	1.178
70		.459	1190	1.67	5808	2985	1375	468	733	4350	1520	2002	1301	74.55	75.37	.7944	2.178	3470	21.1	1622	64.02	.0110	1.168
71		.460	1188	1.67	5808	3230	1373	483	734	4430	1600	2138	1375	73.30	74.20	.8320	2.072	3389	20.4	1720	63.68	.0122	1.164
72		-----	1184	1.87	6808	3596	-----	484	676	4504	-----	2298	1485	-----	-----	-----	1.960	-----	-----	-----	-----	-----	-----
73		.471	1181	1.87	4719	1250	1378	510	880	2824	1143	1329	998	49.15	49.50	.7884	1.974	3221	17.2	1154	59.97	.0071	1.148
74		.467	1195	1.87	4719	1446	1387	501	857	2781	1197	1426	1045	50.73	51.13	.7844	1.933	3152	17.0	1240	60.36	.0078	1.146
75		.464	1188	1.87	4719	1698	1377	499	868	2792	1255	1628	1106	49.10	49.54	.8037	1.827	3084	18.8	1305	59.35	.0090	1.138
76		.480	1188	1.87	4719	1705	1374	502	884	2841	1325	1624	1173	48.84	49.31	.8298	1.749	3010	18.3	1358	59.68	.0097	1.128
77		.472	1184	1.87	4719	1910	1379	493	882	2903	1400	1733	1246	81.61	82.04	.8772	1.675	2929	18.8	1474	63.52	.0103	1.124
78		.467	1186	1.87	3630	882	1377	486	574	1887	985	1222	900	37.89	37.94	.8918	1.810	2581	11.3	1048	58.71	.0086	1.092
79		.460	1183	1.87	3630	972	1388	483	572	1927	1023	1274	944	37.53	37.80	.8698	1.568	2612	10.4	1100	56.78	.0072	1.084
80		.468	1186	1.87	3630	1080	1370	488	579	2027	1103	1342	1017	38.72	37.01	.7415	1.510	2521	10.8	1178	56.88	.0080	1.085
81		.469	1182	1.87	3630	1125	1373	485	579	2076	1130	1388	1043	38.24	36.55	.7527	1.486	2493	10.4	1208	56.87	.0088	1.083
82	30,000	0.832	605	1.15	7260	1979	781	458	808	3728	1480	1245	1188	57.07	57.62	0.8541	2.995	4392	30.8	1872	56.39	0.0096	1.267
83		.819	616	1.15	7260	2255	797	475	857	3892	1615	1356	1283	56.49	57.12	.8893	2.870	4218	30.0	1770	56.13	.0111	1.268
84		.607	621	1.15	7260	2480	796	471	844	3997	1693	1440	1360	58.50	57.19	.8835	2.778	4125	29.1	1867	56.08	.0122	1.245
85		.621	614	1.15	7260	2810	797	465	845	4138	1833	1541	1467	58.88	57.44	.8562	2.683	4007	27.7	2010	56.33	.0138	1.229
86		-----	620	1.15	7260	3020	797	463	844	4202	-----	1599	1318	-----	-----	-----	2.828	-----	-----	-----	-----	-----	-----
87		.621	626	1.15	8897	1710	812	475	801	3593	1393	1198	1099	57.00	57.48	.8410	2.898	4289	30.2	1821	56.49	.0083	1.266
88		.621	619	1.15	8897	1906	803	475	810	3659	1477	1290	1177	58.33	58.88	.8379	2.804	4178	29.7	1813	56.84	.0084	1.256
89		.611	622	1.15	8897	2118	800	471	818	3748	1573	1342	1265	58.25	58.84	.8454	2.793	4088	28.7	1736	57.11	.0104	1.245
90		.610	620	1.15	8897	2490	797	469	826	3888	1710	1467	1393	58.20	58.53	.8497	2.850	3901	27.5	1893	57.37	.0124	1.228
91		.618	615	1.15	8897	2938	795	466	832	4048	1837	1601	1541	58.57	58.38	.8519	2.527	3784	26.8	2087	57.42	.0147	1.206
92		.628	615	1.15	8353	1323	802	476	762	3111	1270	1047	1000	51.17	51.54	.8413	2.871	4125	29.8	1387	58.70	.0072	1.270
93		.619	619	1.15	8353	1446	801	479	770	3149	1337	1098	1070	50.87	51.27	.8191	2.875	4029	28.1	1449	58.28	.0079	1.260
94		.624	618	1.15	8353	1567	804	477	772	3226	1370	1148	1107	51.07	51.51	.8067	2.810	3983	27.5	1491	53.83	.0085	1.258
95		.616	618	1.15	8353	1688	798	479	779	3258	1430	1197	1161	50.46	50.98	.8182	2.722	3902	27.2	1580	56.02	.0083	1.232
96		.624	617	1.15	8353	1786	802	479	781	3302	1455	1232	1194	50.89	51.19	.7936	2.680	3874	26.8	1577	58.08	.0086	1.219
97		.623	615	1.15	5808	997	799	477	720	2800	1150	921	818	46.04	46.32	.8319	2.823	3951	27.3	1251	58.78	.0080	1.267
98		.611	624	1.15	5808	1189	802	476	724	2850	1240	993	1006	46.14	46.46	.8162	2.669	3816	25.9	1352	58.20	.0070	1.253
99		.619	622	1.15	5808	1333	805	474	730	2723	1315	1062	1082	46.18	46.53	.8033	2.564	3711	25.3	1439	58.34	.0080	1.215
100		.616	621	1.15	5808	1498	802	475	737	2754	1400	1116	1164	46.72	46.14	.8017	2.468	3606	24.3	1529	58.54	.0091	1.203
101		.622	616	1.15	5808	1614	800	474	745	2779	1477	1156	1233	45.47	45.92	.8130	2.406	3318	24.2	1618	60.23	.0099	1.198
102		.627	621	1.15	4719	641	809	478	858	1701	963	750	808	32.34	32.52	.7947	2.298	3493	21.4	1050	55.56	.0065	1.192
103		.621	621	1.15	4719	703	805	471	858	1738	1016	786	853	31.18	31.35	.8130	2.211	3407	20.8	1120	55.86	.0063	1.180
104		.624	618	1.15	4719	773	804	475	845	1764	1070	820	905	31.03	31.24	.8190	2.151	3325	20.3	1175	54.38	.0069	1.182
105		.613	622	1.15	4719	867	801	471	847	1805	1157	859	987	30.80	30.84	.8216	2.077	3204	19.8	1276	54.70	.0079	1.172
106		.622	619	1.15	4719	984	804	471	834	1864	1230	911	1055	29.70	30.17	.8187	2.048	3113	19.8	1367	53.53	.0090	1.166
107		.614	618	1.15	3630	528	787	470	582	1147	800	688	711	23.35	23.90	.7939	1.717	2937	14.4	884	56.00	.0062	1.128
108		.619	620	1.15	3630	562	802	468	567	1154	823	694	741	23.95	24.11	.7528	1.683	2899	12.6	913	55.94	.0085	1.111
109		.626	620	1.15	3630	579	807	469	565	-----	-----	774	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
110		.628	617	1.15	3630	805	803	468	564	1206	907	729	820	23.19	23.56	.7371	1.864	2787	12.8	1006	54.55	.0072	1.106
111		.618	612	1.20	7260	2060	791	460	793	3613	1470	1259	1178	57.18	57.78	.8289	2.870	4405	29.1	1658	58.15	.0100	1.246
112		.621	611	1.20	7260	2250	792	460															

TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Continued



Run	Altitude (ft)	M0	P0 (lb /sq ft)	Turbine nozzle area (sq ft)	N (rpm)	Wf (lb /hr)	P2 (lb /sq ft)	T2 (°R)	T4 (°R)	P5 (lb /sq ft)	T5 (°R)	P6 (lb /sq ft)	T6 (°R)	W0.1 (lb /sec)	W0.5 (lb /sec)	ηt	P5/P0	N √θ5 (rpm)	Δht θ5 (Btu /lb)	T5 θ5 (°R)	W0.5√θ5 (lb /sec)	Wf W0.1(3600)	T5 T6	
113	30,000	0.618	614	1.20	7260	2590	784	482	809	3808	1810	1582	1301	57.02	57.68	0.8006	2.754	4221	28.4	1810	57.88	0.0118	1.238	
114		.614	614	1.20	7260	2590	782	459	812	3888	1673	1445	1365	57.02	57.74	.8308	2.691	4149	27.4	1880	57.92	.0126	1.226	
115		.614	614	1.20	7260	2765	792	458	815	3860	1733	1509	1422	56.89	57.76	.8341	2.624	4081	28.9	1962	57.93	.0135	1.219	
116		.618	612	1.20	6897	1770	790	463	774	3434	1367	---	1086	56.23	56.72	---	---	4350	29.6	1532	57.73	.0087	1.259	
117		.626	612	1.20	6897	2020	797	482	785	3375	1480	1292	1196	56.66	57.22	.8264	2.767	4173	28.2	1884	56.59	.0099	1.237	
118		.621	617	1.20	6897	2305	801	462	795	3722	1590	1404	1294	56.86	57.50	.8433	2.651	4054	27.4	1797	56.58	.0115	1.229	
119		.611	614	1.20	6897	2595	789	460	804	3786	1713	1492	1412	56.88	56.70	.8391	2.544	3899	28.2	1932	56.92	.0129	1.213	
120		.616	615	1.20	6897	2865	784	478	859	3880	1860	1585	1344	54.71	55.55	.8618	2.453	3753	26.7	2016	56.97	.0181	1.205	
121		.634	605	1.20	6897	3030	792	460	813	3974	1847	1621	1540	55.83	56.77	.8560	2.452	3783	25.0	2083	58.67	.0150	1.189	
122		.624	612	1.20	6353	1375	795	482	738	3048	1177	1074	912	52.79	53.17	.9154	2.858	4278	30.3	1325	56.33	.0072	1.281	
123		.614	608	1.20	6353	1515	784	480	740	3099	1277	1121	1019	51.99	52.41	.8487	2.764	4117	28.1	1440	57.01	.0081	1.283	
124		.619	612	1.20	6353	1700	792	480	746	3008	1355	1204	1099	52.43	52.90	.8298	2.684	4006	27.0	1628	57.56	.0090	1.233	
125		.634	607	1.20	6353	1910	798	481	753	3507	1440	1274	1183	52.37	52.90	.8106	2.598	3885	26.3	1621	57.54	.0101	1.217	
126		.628	615	1.20	6353	2095	802	481	758	3401	1530	1368	1267	52.70	53.28	.8217	2.490	3784	25.2	1723	58.21	.0110	1.208	
127		.624	612	1.20	5808	1030	796	480	686	2542	1080	932	860	46.77	47.06	.8477	2.727	4070	27.0	1218	57.13	.0061	1.256	
128		---	---	1.20	5808	1112	---	457	659	2589	---	966	901	---	---	---	2.680	---	---	---	---	---	---	---
129		.621	606	1.20	5808	1245	785	457	685	2834	1200	1014	971	45.87	46.22	.8424	2.597	3977	25.8	1563	57.27	.0075	1.258	
130		.614	610	1.20	5808	1334	787	480	701	2883	1243	1054	1018	45.77	46.14	.8210	2.527	3811	24.8	1402	57.57	.0061	1.220	
131		.633	612	1.20	5808	1436	801	460	705	2786	1280	1102	1061	46.36	46.78	.7985	2.510	3762	24.2	1444	57.47	.0086	1.206	
132		.624	605	1.20	4719	700	788	459	614	1695	940	748	796	32.40	32.59	.7836	2.272	3535	20.1	1062	55.17	.0060	1.181	
133		.624	609	1.20	4719	710	782	458	613	1684	950	760	809	32.87	33.07	.7510	2.219	3518	19.9	1075	56.84	.0060	1.174	
134		.629	609	1.20	4719	738	785	458	612	1693	973	782	850	32.66	33.05	.7858	2.165	3475	19.4	1107	57.05	.0062	1.172	
135		.630	607	1.20	4719	800	783	459	619	1751	1043	818	893	33.27	33.49	.7785	2.115	3364	19.2	1179	56.60	.0067	1.168	
136		.630	609	1.20	4719	910	785	458	622	1788	1123	871	970	33.00	33.26	.7727	2.050	3248	17.9	1271	56.88	.0077	1.158	
137		.624	605	1.20	4719	985	786	457	630	---	---	908	1017	---	---	---	---	---	---	---	---	---	---	---
138		.623	607	1.20	3630	580	789	460	546	1153	790	668	706	23.76	23.91	.7590	1.896	2956	13.8	891	55.35	.0066	1.118	
139		.624	607	1.20	3630	580	788	459	548	1128	800	---	713	23.79	23.89	---	---	2959	13.7	904	58.05	.0065	1.122	
140		.624	610	1.20	3630	580	783	489	546	1149	810	685	726	23.51	23.67	.7704	1.877	2920	13.5	916	54.73	.0069	1.118	
141		.628	608	1.20	3630	630	792	480	549	1174	855	710	773	23.06	23.23	.7588	1.858	2847	12.8	984	54.07	.0076	1.106	
142		.626	610	1.20	3630	660	794	480	552	1204	905	736	822	22.22	22.90	.7203	1.836	2771	12.1	1021	53.54	.0081	1.101	
143		.616	611	1.30	7260	2020	789	453	778	3497	1473	1268	1185	57.49	58.05	.8590	2.760	4400	28.7	1690	60.40	.0088	1.243	
144		.622	607	1.30	7260	2350	788	454	784	3636	1593	1366	1283	57.27	57.92	.8488	2.685	4243	27.7	1821	60.41	.0114	1.232	
145		.626	605	1.30	7260	2848	787	456	806	3759	1703	1448	1363	58.97	57.70	.8621	2.594	4113	27.0	1943	60.40	.0128	1.223	
146		.625	607	1.30	7260	2975	789	456	817	3888	1810	1557	1498	58.90	57.73	.8476	2.496	4000	26.1	2060	60.38	.0145	1.208	
147		.630	622	1.30	7260	3245	787	457	821	3965	1890	1627	1582	56.66	57.58	.8509	2.456	3922	25.1	2147	60.44	.0158	1.193	
148		.613	611	1.30	6897	1808	787	459	783	3336	1403	1240	1127	56.23	56.73	.8618	2.890	4279	28.5	1685	60.23	.0089	1.245	
149		.619	615	1.30	6897	2050	796	460	775	3480	1493	1294	1210	56.83	57.40	.8378	2.689	4155	27.8	1684	60.42	.0100	1.234	
150		.613	621	1.30	6897	2390	800	460	785	3631	1610	1420	1321	57.03	57.69	.8459	2.567	4010	26.7	1816	60.63	.0118	1.219	
151		.618	620	1.30	6897	2775	802	461	798	3788	1743	1547	1447	56.94	57.71	.8477	2.447	3868	25.5	1963	60.71	.0136	1.205	
152		.618	620	1.30	6897	3125	802	459	804	3933	1853	1657	1559	56.81	57.68	.8263	2.374	3759	24.1	2094	60.34	.0153	1.189	
153		.621	620	1.30	6353	1490	804	463	751	3033	1266	1110	1034	53.48	53.89	.8318	2.732	4104	27.1	1440	60.14	.0077	1.243	
154		.622	617	1.30	6353	1683	801	462	758	3106	1367	1191	1115	53.06	53.52	.8273	2.608	3988	26.4	1537	60.25	.0088	1.226	
155		.626	617	1.30	6353	1908	803	463	746	3222	1463	1284	1207	53.01	53.84	.8247	2.509	3864	25.5	1640	60.24	.0100	1.212	
156		.628	606	1.30	6353	2090	789	463	753	3241	1543	1338	1291	51.89	52.47	.8044	2.422	3768	24.3	1730	60.42	.0112	1.185	
157		.627	616	1.30	6353	2390	801	463	759	3357	1643	1450	1381	52.55	53.19	.8251	2.358	3682	23.8	1842	60.58	.0126	1.180	
158		.607	613	1.30	6808	1083	788	460	686	2462	1130	955	907	46.15	46.45	.8534	2.633	3986	26.4	1275	59.59	.0085	1.246	
159		.621	607	1.30	5808	1480	787	462	705	2639	1347	1112	1128	46.71	48.12	.8066	2.375	3671	25.6	1514	60.63	.0090	1.196	
160		.614	613	1.30	5808	1690	791	462	712	2717	1443	1190	1228	45.82	46.09	.7732	2.283	3554	22.1	1822	61.09	.0103	1.175	
161		.616	606	1.30	5808	1875	786	482	720	2744	1567	1247	1358	45.18	45.70	.8115	2.200	3420	21.5	1781	62.65	.0115	1.174	
162		.619	619	1.30	5808	2080	801	462	724	2846	1643	1315	1418	45.75	46.33	.7799	2.164	3348	20.6	1847	62.81	.0128	1.180	
163		.634	615	1.30	4719	700	806	481	613	1657	---	784	---	35.97	34.16	---	2.168	---	---	---	---	.0057	---	---
164		.616	614	1.30	4719	791	793	481	615	1687	1043	810	890	32.99	33.21	.8078	2.083	3364	19.3	1174	59.63	.0067	1.172	
165		.640	610	1.30	4719	850	803	460	619	1728	1070	846	921	33.06	33.30	.7883	2.043	3323	18.8	1207	59.18	.0071	1.162	
166		.625	612	1.30	4719	961	795	463	631	1764	---	897	---	32.21	32.47	---	1.967	---	---	---	---	.0082	---	---
167		.616	612	1.30	4719	1009	790	465	634	1771	1223	920	1072	31.56	31.84	.7719	1.926	5121	17.1	1384	59.30	.0089	1.141	
168		.636	611	1.30	3630	553	801	461	544	1102	796	672	717	24.92	25.07	.7699	1.640	2846	12.5	895	59.87	.0062	1.108	



TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Continued

Run	Altitude (ft)	M <sub>0</sub>	P <sub>0</sub> (lb /sq ft)	Turbine nozzle area (sq ft)	N (rpm)	W <sub>r</sub> (lb /hr)	P <sub>2</sub> (lb /sq ft)	T <sub>2</sub> (°R)	T <sub>4</sub> (°R)	P <sub>5</sub> (lb /sq ft)	T <sub>5</sub> (°R)	P <sub>8</sub> (lb /sq ft)	T <sub>8</sub> (°R)	W <sub>a,1</sub> (lb /sec)	W <sub>g,5</sub> (lb /sec)	η <sub>t</sub>	P <sub>5</sub> /P <sub>8</sub>	N √g <sub>5</sub> (rpm)	Δh <sub>t</sub> g <sub>5</sub> (Btu /lb)	T <sub>5</sub> g <sub>5</sub> (°R)	W <sub>g,5</sub> √g <sub>5</sub> g <sub>5</sub> (lb /sec)	W <sub>r</sub> W <sub>a,1</sub> (sec/00)	T <sub>5</sub> T <sub>6</sub>
169	30,000	0.621	810	1.30	3630	635	791	480	546	1146	883	706	778	25.44	25.82	0.7811	1.828	2834	12.8	974	56.80	0.0075	1.109
170		.636	810	1.30	3630	698	801	480	580	1186	820	743	836	25.33	25.52	.7838	1.598	2748	12.0	1038	58.31	.0083	1.102
171		.599	823	1.37	7260	2130	784	468	798	3488	1527	1277	1234	56.95	57.54	.8388	2.751	4327	26.0	1693	81.22	.0104	1.237
172		.619	808	1.37	7260	2315	787	468	808	-----	1807	1334	1304	58.44	57.08	-----	-----	4228	27.8	1779	-----	.0114	1.232
173		.609	818	1.37	7260	2618	794	469	818	3678	1700	1437	1394	56.75	57.48	.8535	2.559	4118	26.7	1682	81.42	.0128	1.220
174		.618	804	1.37	7260	2780	780	468	860	3699	1767	1482	1456	55.75	58.52	.8615	2.498	4042	26.0	1960	81.31	.0139	1.214
175		.579	822	1.37	7260	3015	781	469	824	3794	1840	1569	1529	56.57	58.41	.8653	2.434	3989	25.4	2037	80.93	.0151	1.203
176		.619	816	1.37	6897	1690	797	467	788	3331	1450	1226	1160	56.49	57.02	.8267	2.717	4235	27.2	1589	81.35	.0095	1.233
177		.621	807	1.37	6897	2260	787	467	788	3495	1604	1368	1319	55.68	56.33	.8482	2.617	4019	26.1	1762	81.40	.0117	1.218
178		.628	804	1.37	6897	2590	788	467	785	3606	1685	1471	1398	55.87	58.59	.8418	2.451	3928	25.3	1872	81.17	.0129	1.205
179		.629	810	1.37	6897	2676	796	468	801	3726	1777	1568	1484	56.27	57.07	.8513	2.376	3832	24.7	1978	81.63	.0142	1.197
180		.618	820	1.37	6897	3265	802	468	811	3803	1897	1697	1602	56.39	57.81	.8453	2.300	3718	24.1	2111	81.21	.0162	1.184
181		.618	812	1.37	6353	1535	-----	466	730	2946	1300	1104	1098	52.44	52.87	.8071	2.668	4083	28.0	1447	81.12	.0081	1.228
182		.622	805	1.37	6353	1686	-----	468	741	3017	1377	1174	1135	51.70	52.17	.8009	2.570	3973	25.4	1527	80.71	.0081	1.213
183		.629	805	1.37	6353	1890	-----	467	747	3114	1435	1255	1217	51.91	52.44	.8013	2.481	3884	24.8	1626	81.06	.0101	1.202
184		.634	805	1.37	6353	2080	-----	467	751	3188	1533	1328	1280	52.09	52.67	.8176	2.403	3782	24.0	1703	81.44	.0111	1.198
185		.627	812	1.37	6353	2216	-----	466	750	3255	1570	1371	1322	52.43	53.05	.8078	2.374	3759	23.6	1747	81.38	.0117	1.188
186		.624	806	1.37	6808	1136	-----	464	698	2459	1153	853	845	46.09	46.41	.8050	2.680	3948	24.4	1280	80.30	.0088	1.223
187		.629	803	1.37	5808	1305	-----	465	695	2524	1255	1027	1058	45.92	46.28	.8102	2.458	3796	23.8	1397	81.25	.0079	1.209
188		.626	806	1.37	5808	1479	-----	466	702	2607	1323	1095	1111	45.66	46.07	.7842	2.581	3702	22.7	1472	80.75	.0090	1.191
189		.634	809	1.37	5808	1602	-----	464	704	2660	1380	1151	1171	46.31	46.76	.7718	2.511	3632	22.2	1544	81.47	.0098	1.176
190		.630	805	1.37	5808	1720	-----	463	708	2702	1440	1185	1224	45.69	46.17	.7798	2.280	3559	22.1	1614	81.67	.0105	1.176
191		.619	808	1.37	4719	717	787	463	614	1615	987	755	841	35.07	35.27	.7792	2.148	3482	19.8	1108	80.83	.0080	1.174
192		.625	809	1.37	4719	743	795	463	614	1628	1003	789	857	35.31	35.52	.7790	2.120	3425	19.5	1124	81.12	.0082	1.170
193		.647	805	1.37	4719	851	801	464	619	1692	1087	829	920	35.24	35.40	.7794	2.041	3328	18.4	1194	80.67	.0071	1.180
194		.628	803	1.37	4719	817	788	465	625	1698	1150	862	995	32.14	32.39	.8072	1.970	3212	18.0	1282	80.88	.0079	1.158
195		.650	803	1.37	4719	1050	801	462	627	1790	1200	930	1083	32.09	32.38	.8094	1.925	3150	13.3	1549	59.07	.0091	1.108
196		.626	596	1.37	3830	898	778	462	648	1083	820	858	758	25.71	25.87	.7704	1.846	2904	12.8	922	56.93	.0068	1.111
197		.618	606	1.37	3830	817	781	463	648	1110	850	877	787	23.46	23.63	.7597	1.840	2654	13.0	955	57.98	.0073	1.108
198		.625	597	1.37	3830	855	777	463	651	1138	917	711	854	22.93	23.11	.7438	1.801	2752	12.1	1028	87.69	.0079	1.100
199		.633	610	1.37	3830	875	798	462	653	1179	946	741	857	25.29	25.58	.7752	1.691	2713	12.3	1082	57.88	.0080	1.103
200		.625	608	1.67	7260	2245	791	456	763	3488	1530	1267	1239	57.52	58.14	.8435	2.695	4324	27.7	1741	82.28	.0108	1.235
201		.618	612	1.67	7260	2375	791	459	787	3528	1690	1337	1302	57.23	57.89	.8239	2.637	4246	26.7	1797	82.26	.0115	1.221
202		.625	610	1.67	7260	2500	783	459	790	3574	1850	1384	1359	57.35	58.04	.8239	2.682	4172	26.1	1865	82.90	.0121	1.214
203		.627	608	1.67	7260	2826	792	458	792	3622	1650	1430	1358	57.59	58.12	.8416	2.633	4175	26.1	1868	82.04	.0127	1.214
204		.621	610	1.67	7260	2785	791	458	796	3602	1720	1471	1427	57.18	57.93	.8260	2.603	4087	26.4	1947	82.25	.0135	1.205
205		.623	607	1.67	7260	3080	789	460	806	3744	1810	1553	1507	56.61	57.87	.8538	2.411	4000	25.2	2042	82.84	.0151	1.201
206		.623	608	1.67	6897	1995	790	460	766	-----	1443	1238	1178	56.40	58.95	-----	-----	4222	26.8	1828	-----	.0098	1.225
207		.623	608	1.67	6897	2270	790	460	766	3407	1548	1334	1277	56.38	57.01	.8167	2.554	4068	25.8	1748	82.53	.0112	1.212
208		.624	608	1.67	6897	2540	790	459	773	3523	1643	1441	1370	56.50	57.21	.8167	2.445	3974	24.8	1857	82.70	.0128	1.199
209		.619	614	1.37	6897	2845	795	459	780	3850	1730	1603	1448	56.75	57.54	.8393	2.388	3882	24.0	1958	82.85	.0139	1.195
210		.625	608	1.67	6897	3015	791	459	767	3724	1793	1601	1506	56.28	57.12	.8449	2.326	3817	23.9	2028	82.07	.0149	1.191
211		.621	610	1.67	6353	1626	791	459	761	2945	1270	1132	1031	52.88	53.51	.8353	2.600	4128	26.3	1435	80.95	.0085	1.232
212		.625	610	1.67	6353	1880	794	462	733	3045	1428	1234	1185	52.64	53.18	.8112	2.488	3907	24.6	1605	82.55	.0099	1.205
213		.621	608	1.67	6353	2100	788	459	736	3130	1500	1318	1257	52.28	52.86	.8088	2.380	3820	23.8	1695	82.08	.0112	1.183
214		.625	608	1.67	6353	2220	791	459	758	3172	1543	1387	1298	52.42	53.04	.8198	2.338	3788	23.6	1744	82.41	.0116	1.191
215		.621	609	1.67	6353	2410	789	459	745	3263	1620	1428	1365	52.18	52.83	.8308	2.288	3685	22.9	1831	82.04	.0128	1.187
216		.625	610	1.67	5808	1209	794	462	681	2432	1160	971	939	46.70	47.04	.8333	2.503	3954	24.8	1293	81.67	.0072	1.225
217		.625	609	1.67	5808	1427	792	461	684	2476	1200	1009	987	46.58	46.92	.8267	2.454	3878	24.0	1351	81.84	.0078	1.218
218		.624	609	1.67	5808																		

TABLE I. - VARIABLE-AREA TURBINE PERFORMANCE - Concluded



Run	Altitude (ft)	M <sub>0</sub>	P <sub>0</sub> ( $\frac{lb}{sq\ ft}$ )	Turbine nozzle area (sq ft)	N (rpm)	W <sub>c</sub> ( $\frac{lb}{hr}$ )	P <sub>2</sub> ( $\frac{lb}{sq\ ft}$ )	T <sub>2</sub> (°R)	T <sub>4</sub> (°R)	P <sub>5</sub> ( $\frac{lb}{sq\ ft}$ )	T <sub>5</sub> (°R)	P <sub>6</sub> ( $\frac{lb}{sq\ ft}$ )	T <sub>6</sub> (°R)	W <sub>a,1</sub> ( $\frac{lb}{sec}$ )	W <sub>a,5</sub> ( $\frac{lb}{sec}$ )	$\eta_t$	P <sub>5</sub> /P <sub>6</sub>	$\frac{N}{\sqrt{P_5}}$ (rpm)	$\frac{\Delta h_t}{P_5}$ ( $\frac{Btu}{lb}$ )	$\frac{T_5}{P_5}$ (°R)	$\frac{W_{a,5}\sqrt{P_5}}{P_5}$ ( $\frac{lb}{sec}$ )	W <sub>a,1</sub> (3600)	$\frac{T_5}{P_5}$	
224	30,000	0.618	804	1.87	4719	980	781	458	615	1673	1150	856	988	32.22	32.49	0.7604	1.964	3239	16.8	1279	61.45	0.0083	1.144	
225		.642	805	1.87	4719	1160	785	457	623	1816	1263	960	1121	31.65	31.97	.7252	1.892	3074	16.0	1435	59.06	.0102	1.127	
226		.624	808	1.87	3830	610	791	459	543	1087	827	---	753	24.24	24.41	---	---	2892	12.0	935	59.74	.0070	1.098	
227		.619	810	1.87	3830	620	790	458	543	1102	840	881	785	24.22	24.39	.7116	1.618	2870	11.8	949	59.92	.0071	1.098	
228		.629	807	1.87	3830	640	792	458	542	1111	855	891	782	24.31	24.49	.6904	1.608	2847	11.6	968	60.21	.0075	1.093	
229		.621	808	1.87	3830	670	788	458	544	1129	900	714	825	23.78	23.98	.6894	1.581	2777	11.0	1019	59.61	.0078	1.091	
230		.625	808	1.87	3830	738	792	459	549	1174	975	746	893	23.10	23.30	.7213	1.574	2873	11.3	1102	58.10	.0088	1.092	
231	40,000	0.541	576	1.20	7260	1252	408	436	680	1997	1487	695	1251	30.69	31.04	.6167	2.873	4408	21.4	1748	56.47	.0113	1.173	
232		.527	575	1.20	7260	1370	404	436	788	2046	1645	728	1335	30.20	30.58	.6131	2.809	4182	27.9	1955	57.76	.0126	1.231	
233		.544	578	1.20	7260	1438	408	436	---	2096	---	747	1382	30.52	30.92	---	2.808	---	---	---	---	.0131	---	
234		.512	578	1.20	6897	1170	405	434	697	1911	1450	888	1201	30.11	30.44	.6688	2.869	4239	23.4	1712	57.09	.0108	1.191	
235		.541	595	1.20	6897	1851	428	434	707	2235	1890	855	1442	31.41	31.87	.6812	2.814	3834	20.8	2011	55.78	.0148	1.185	
236		.544	575	1.20	8353	948	407	433	675	1699	1298	810	1082	28.82	28.88	.7000	2.785	4088	23.6	1556	57.84	.0092	1.200	
237		.544	578	1.20	8353	1187	407	434	668	1825	1468	895	1284	28.58	28.91	.6301	2.623	3857	20.7	1757	57.66	.0116	1.181	
238		.541	575	1.20	8808	791	408	435	670	1436	1248	545	1028	24.75	24.97	.7722	2.845	3804	24.0	1488	57.85	.0089	1.214	
239		.541	576	1.20	8808	970	408	434	665	1489	1415	607	1207	24.23	24.80	.7060	2.483	3590	21.0	1894	58.84	.0111	1.172	
240		.540	575	1.30	7260	1331	408	442	677	1942	1515	697	1306	30.59	30.96	.5969	2.786	4345	19.7	1780	58.90	.0121	1.180	
241		.527	581	1.30	7260	1446	421	437	667	2047	1542	752	1340	31.67	32.07	.5802	2.722	4311	18.4	1832	58.46	.0127	1.151	
242		.503	592	1.30	7260	1562	418	440	670	2095	1622	795	1420	31.32	31.75	.5722	2.642	4211	18.5	1912	58.11	.0139	1.142	
243		.534	586	1.30	7260	1717	417	441	740	2146	1775	834	1510	30.99	31.47	.7128	2.573	4038	22.3	2089	59.01	.0154	1.175	
244		.585	587	1.30	6897	1230	409	435	688	1891	1442	889	1259	30.40	30.74	.6122	2.745	4224	20.6	1719	58.53	.0112	1.164	
245		.526	603	1.30	6897	1561	434	439	678	2029	1500	765	1289	32.10	32.48	.6328	2.852	4147	20.8	1773	58.87	.0118	1.164	
246		.528	594	1.30	6897	1520	424	437	671	2061	1608	808	1398	31.44	31.66	.6190	2.581	4015	18.0	1910	58.86	.0134	1.150	
247		.511	583	1.30	6897	1622	409	435	672	2053	1890	830	1481	30.21	30.66	.6100	2.474	3928	18.1	2014	58.82	.0149	1.141	
248		.527	572	1.30	6353	989	401	438	671	1643	1328	608	1108	28.29	28.66	.7030	2.698	4058	22.8	1573	59.75	.0095	1.183	
249		.551	579	1.30	6353	1100	413	435	672	1742	1398	670	1190	28.89	29.30	.6742	2.600	3948	21.8	1666	59.66	.0105	1.175	
250		.581	568	1.30	8808	804	407	435	661	1400	1240	546	1030	25.18	25.40	.7617	2.564	3815	23.3	1478	60.28	.0089	1.204	
251		.538	574	1.30	8808	970	405	435	669	1480	1402	813	1200	24.22	24.48	.7120	2.382	3603	21.2	1671	59.51	.0111	1.168	
252		.541	574	1.67	7260	1425	405	435	778	1884	1857	714	1338	30.72	31.12	.6424	2.689	4192	27.0	1948	63.64	.0129	1.225	
253		.548	573	1.67	7260	1620	405	438	785	1996	1797	799	1435	30.45	30.90	.6306	2.498	4015	25.4	2131	62.71	.0148	1.204	
254		.538	579	1.67	7260	1750	408	437	791	2041	1870	834	1562	30.52	31.01	.6345	2.447	3941	25.0	2222	62.87	.0159	1.197	
255		.527	589	1.67	6897	1330	407	436	747	1807	1550	882	1278	30.25	30.82	.6039	2.811	4085	26.9	1845	63.39	.0122	1.213	
256		.541	575	1.67	6897	1562	407	438	765	1923	1755	790	1469	30.13	30.58	.6195	2.434	3856	24.4	2081	63.50	.0144	1.196	
257		.538	582	1.67	6897	1725	424	439	771	2023	1823	838	1339	30.60	31.08	.7957	2.414	3787	23.8	2156	62.70	.0167	1.185	
258		.538	574	1.67	6353	1052	403	438	670	1624	1370	638	1168	28.48	28.77	.6878	2.541	3983	21.8	1819	62.03	.0103	1.175	
259		.529	577	1.67	6353	1287	408	437	671	1704	1615	710	1309	28.46	28.81	.6776	2.400	3802	20.1	1800	62.50	.0124	1.157	
260		.561	573	1.67	6353	1391	408	438	726	1756	1633	761	1385	28.54	28.93	.7953	2.307	3674	22.7	1837	63.38	.0135	1.179	
261		.538	573	1.67	5808	854	404	436	683	1382	1273	558	1071	25.09	25.33	.7532	2.441	3771	22.5	1505	62.66	.0095	1.189	
262		.538	573	1.67	5808	1229	404	438	670	1485	1823	894	1420	25.87	24.01	.7144	2.140	3367	18.5	1825	62.03	.0144	1.143	
263	44,000	0.107	503	1.30	7260	1098	306	455	809	1520	1720	565	1405	22.72	23.03	0.8339	2.700	4085	27.4	1973	59.93	0.0134	1.226	
264		.118	297	1.30	7260	1160	300	455	816	1528	1803	579	1485	22.50	22.65	.8228	2.639	4009	26.5	2068	60.06	.0147	1.214	
265		.130	295	1.30	7260	1370	297	452	822	1589	1930	624	1512	22.83	22.61	.8078	2.548	3884	25.2	2214	59.87	.0171	1.197	
266		.125	312	1.30	6897	970	316	454	781	1472	1560	535	1271	22.20	25.07	.8124	2.751	4071	27.2	1783	58.82	.0118	1.227	
267		.158	312	1.30	6897	1072	317	454	787	1500	1656	565	1300	22.91	23.21	.8142	2.653	3952	26.4	1892	59.96	.0130	1.217	
268		.152	312	1.30	6897	1126	317	454	782	1526	1697	582	1400	22.91	23.22	.8128	2.622	3817	25.1	1940	59.77	.0137	1.212	
269		.152	312	1.30	6897	1172	317	454	788	1571	1740	612	1440	22.91	23.24	.8202	2.587	3970	25.8	1989	58.85	.0142	1.208	
270		.162	308	1.30	6353	844	313	448	750	---	---	1427	428	17.77	22.20	---	---	---	---	---	---	.0107	1.212	
271		.125	303	1.30	6353	870	308	444	734	---	---	1460	447	1289	21.68	21.92	---	---	3843	25.3	1730	---	.0111	1.204
272		.138	315	1.67	7260	1319	319	448	789	1580	1810	574	1502	23.95	24.30	.7719	2.718	4000	26.5	2107	63.39	.0163	1.206	
273		.160	308	1.67	7260	1242	311	446	787	1501	1770	505	1472	23.42	23.77	.7046	2.984	4042	26.1	2080	63.62	.0147	1.202	
274		.169	308	1.67	6897	1115	314	445	673	1443	1556	536	1359	22.97	23.28	.5862	2.586	4081	18.9	1815	60.52	.0135	1.144	
275		.141	308	1.67	6897	1130	312	440	695	1446	1607	586	1383	22.98	23.27	.6807	2.546	4017	20.7	1895	61.43	.0137	1.162	
276		.184	310	1.67	6897	1184	317	440	681	1479	1610	587	1402	23.21	23.54	.6193	2.580	4015	19.3	1898	60.79	.0142	1.148	
277		.160	311	1.67	6897	1313	317	440	673	1544	1733	637	1528	23.59	23.75	.5894	2.424	3879	17.7	2043	61.16	.0156	1.134	
278		---	304	1.67	6353	904	---	445	673	---	---	434	1230	---	---	---	---	---	---	---	---	---	---	---

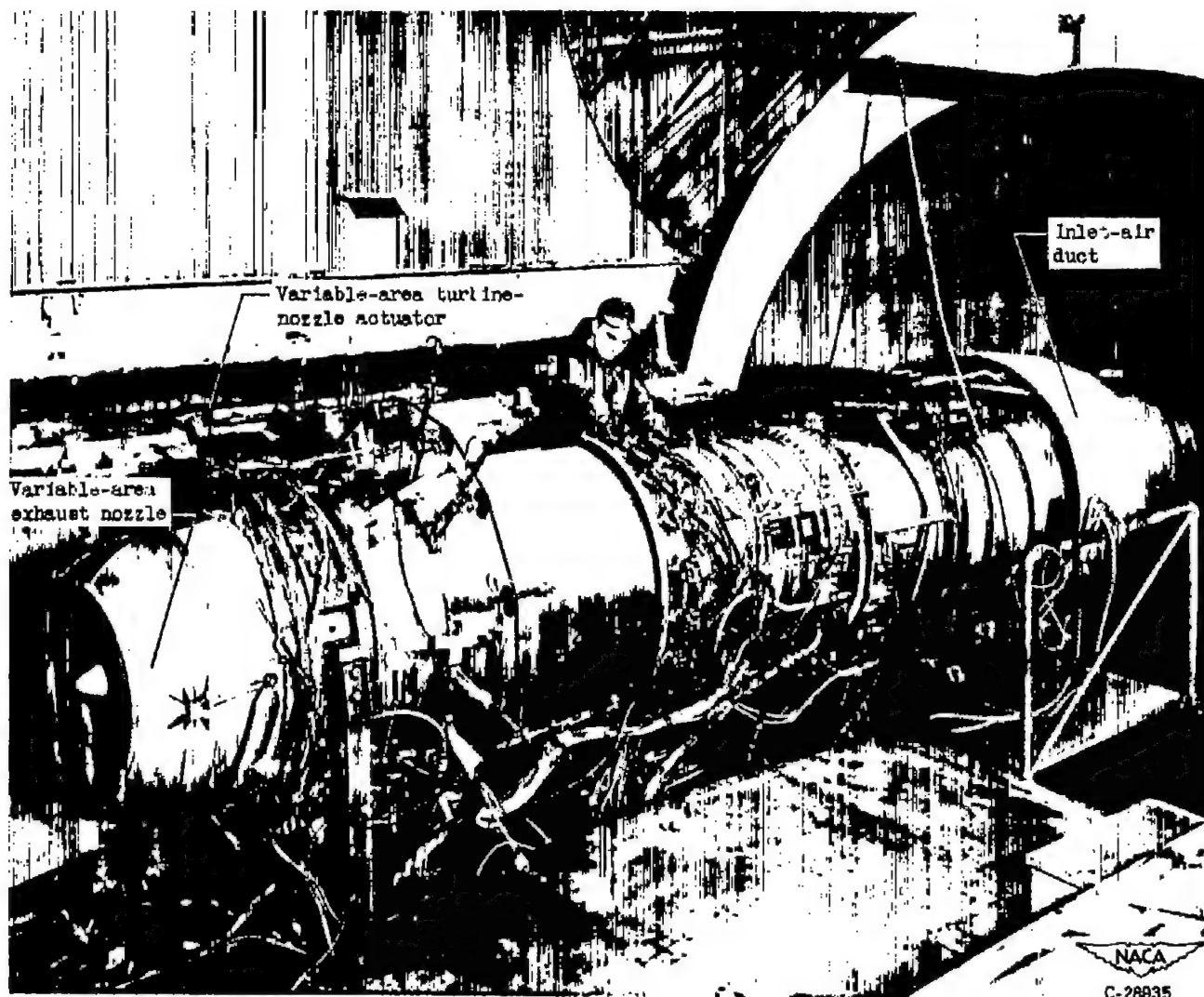
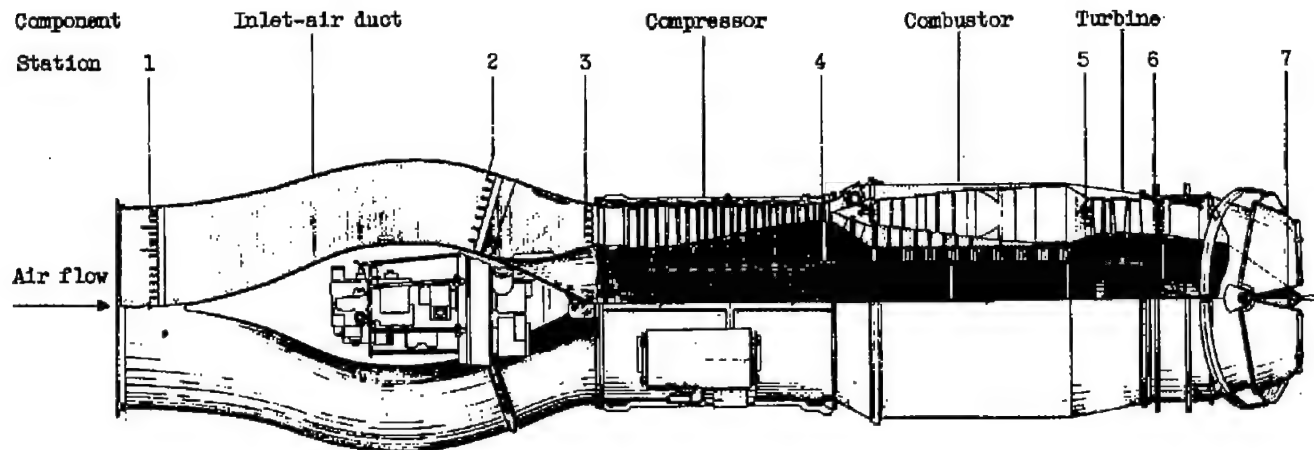


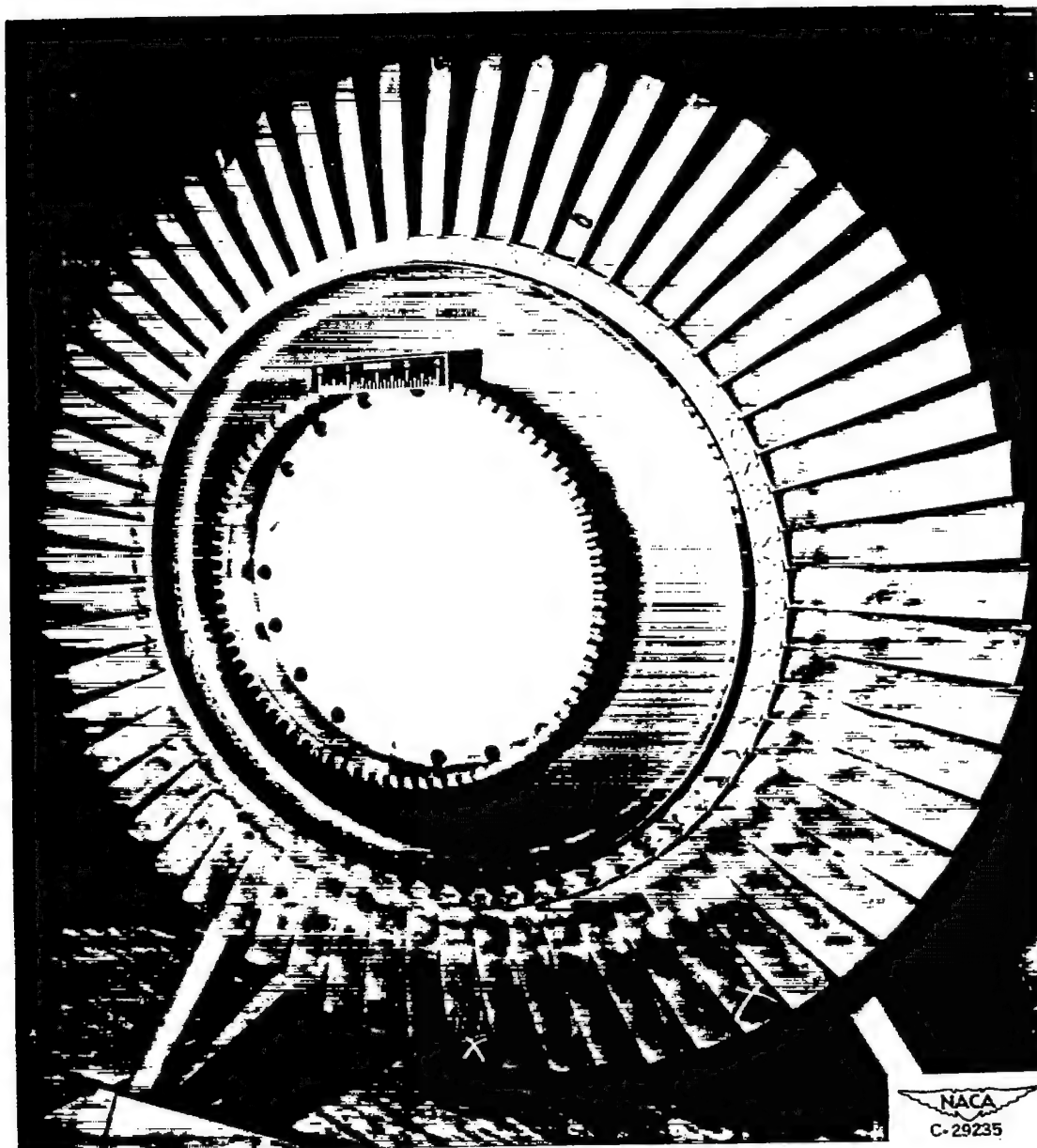
Figure 1. - Installation of turbojet engine in altitude wind tunnel.



Station	Location	Total pressure tubes	Static pressure tubes	Wall static pressure orifices	Thermo-couples
1	Inlet-air duct	29	12	4	10
2	Engine inlet	18	0	4	0
3	Compressor inlet	23	3	7	0
4	Compressor outlet	15	0	2	6
5	Turbine inlet	5	0	0	0
6	Turbine outlet	20	0	8	24
7	Exhaust-nozzle outlet	16	2	8	0

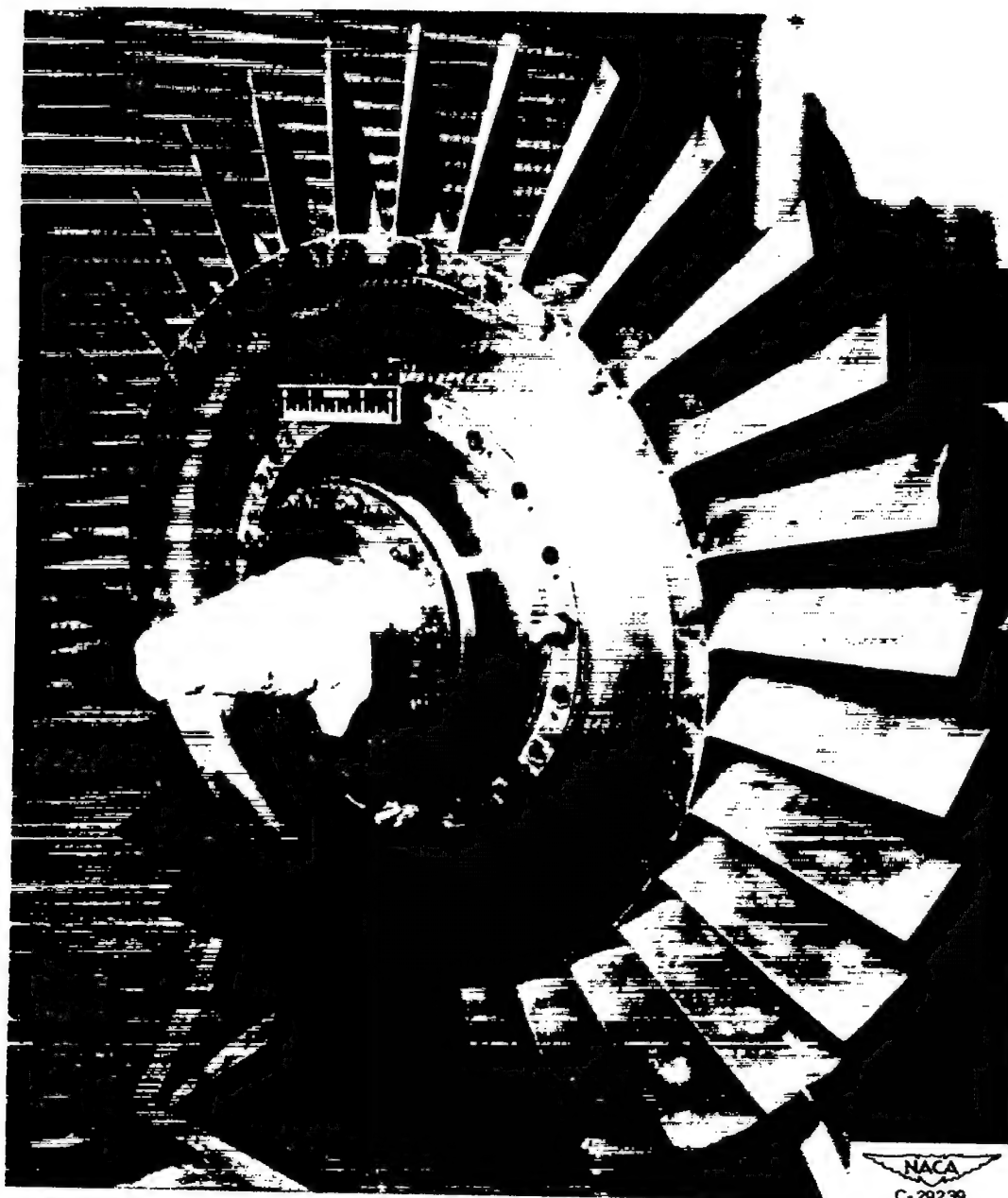
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Figure 2. - Top view of turbojet-engine installation showing stations at which instrumentation was installed



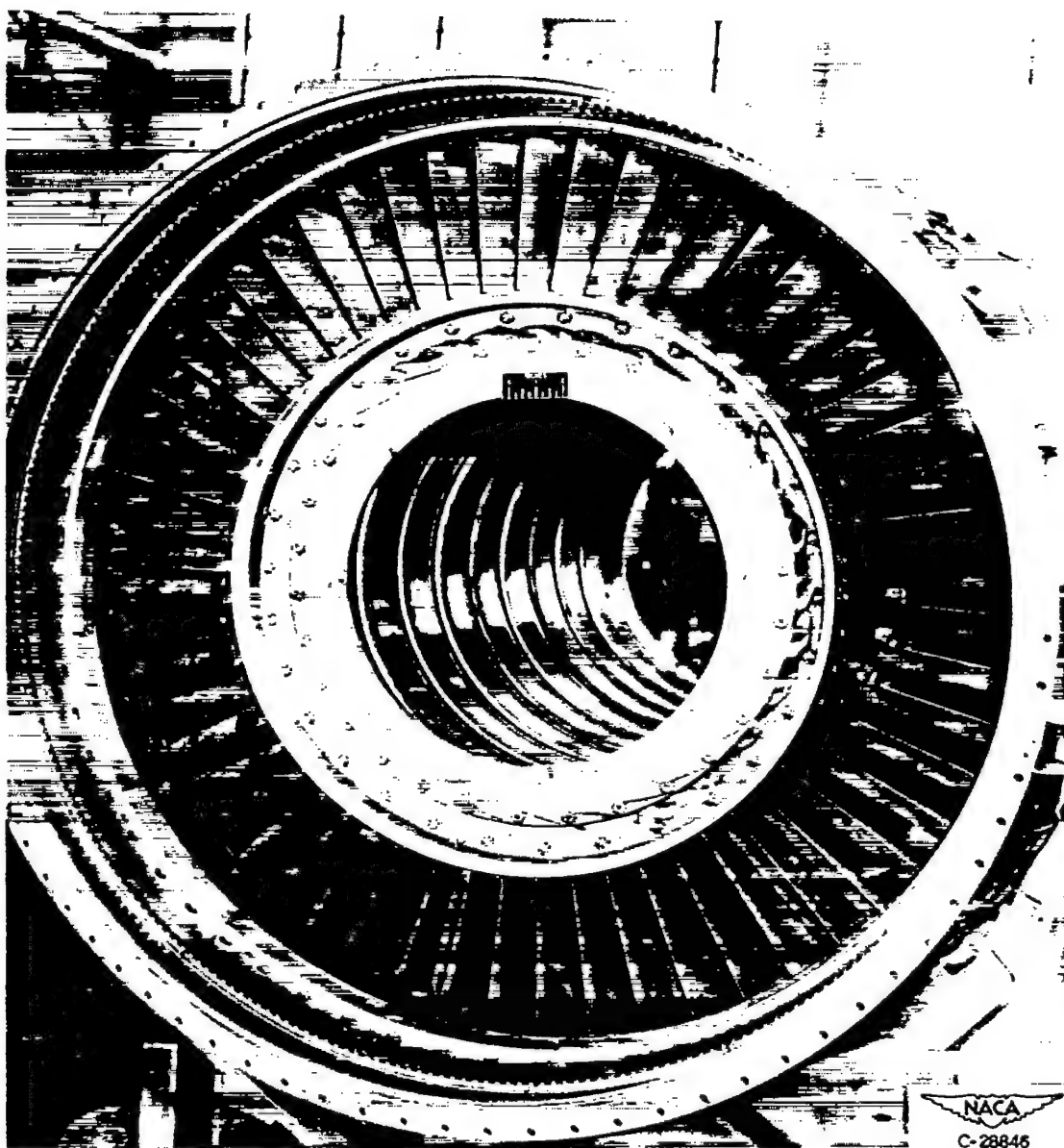
(a) First-stage turbine rotor.

Figure 3. - Photographs of turbine rotors.



(b) Second-stage turbine rotor.

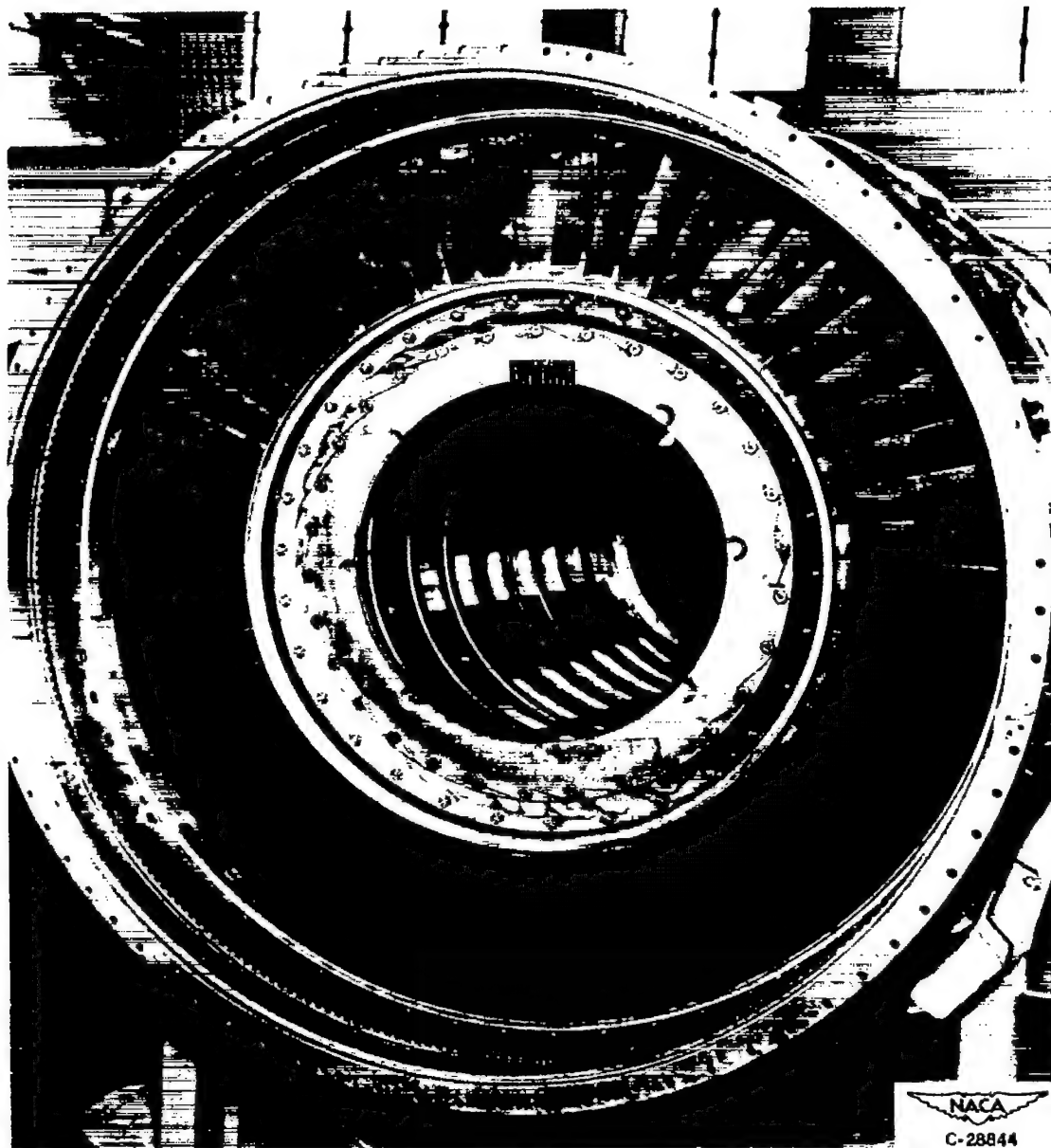
Figure 3. - Concluded. Photographs of turbine rotors.



(a) Open.

Figure 4. - Photographs of variable-area turbine nozzles.





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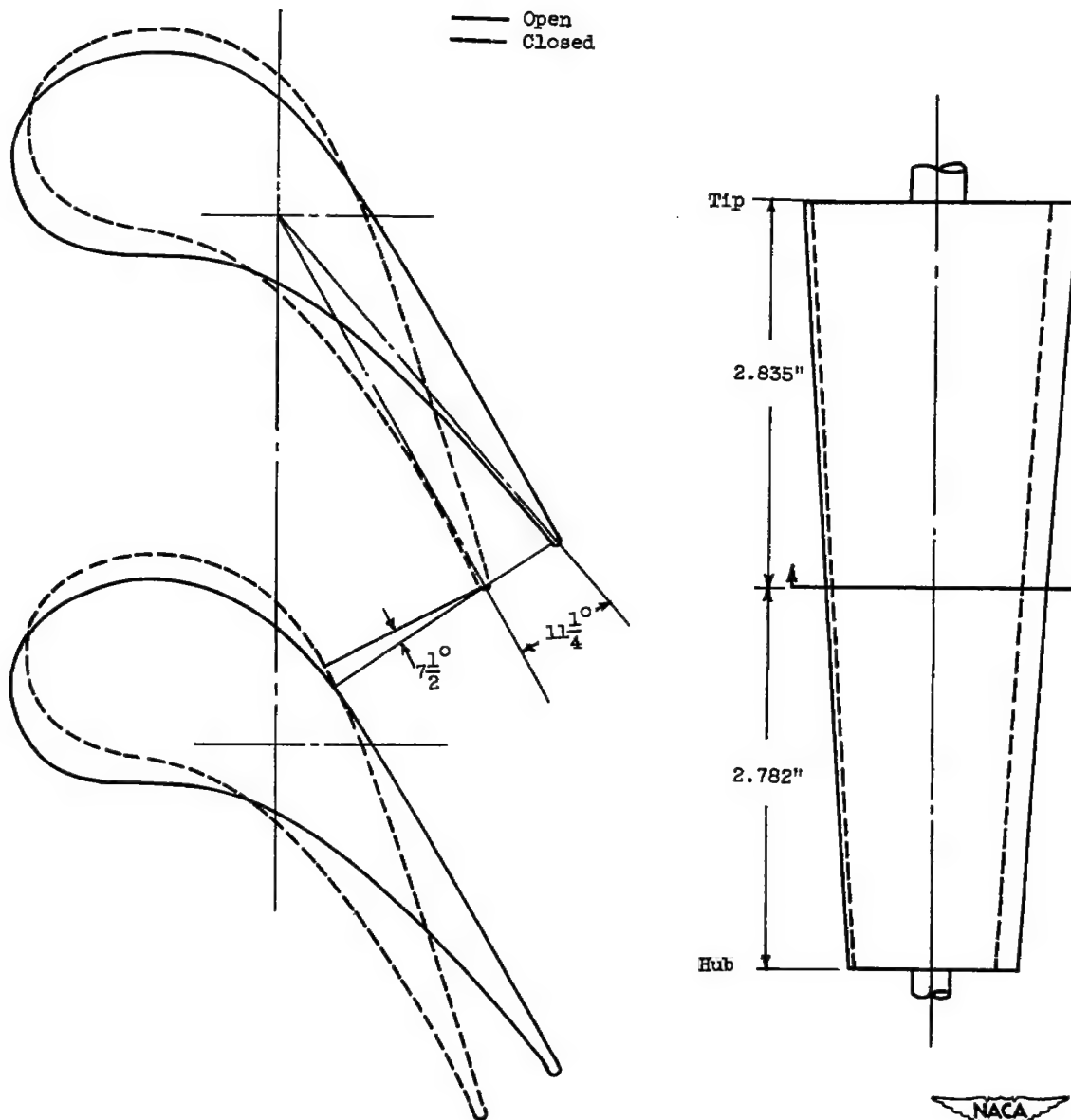
(b) Closed.

Figure 4. - Concluded. Photographs of variable-area turbine nozzles.

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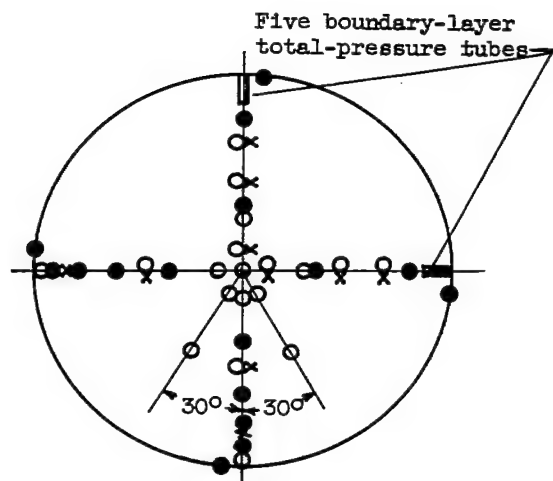
Figure 5. - Schematic sketch of variable-area turbine-nozzle actuating mechanism.



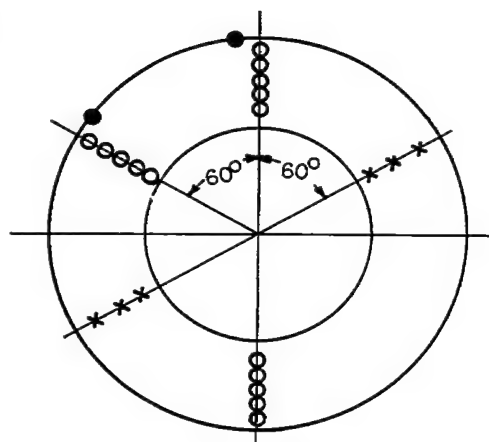
(a) Mid-vane cross-sections of two adjacent vanes ( $2\frac{1}{2}$  times actual size).

(b) Side view of vane (actual size).

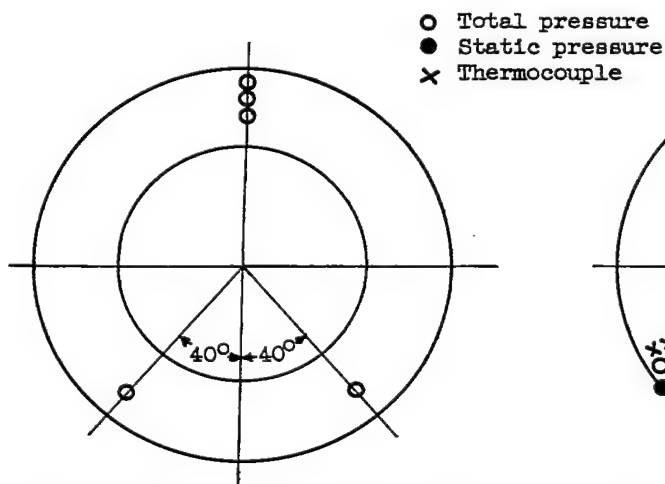
Figure 6. - Sketches of variable-area turbine-nozzle vanes in open and closed positions.



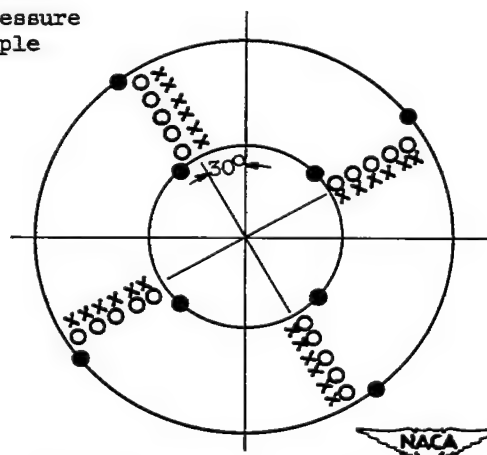
(a) Station 1, cowl inlet. Diameter, 34 inches; location, 6 inches downstream of cowl-inlet flange.



(b) Station 4, compressor outlet. Passage height,  $3\frac{1}{8}$  inches; location,  $\frac{1}{2}$  inch downstream of trailing edge of fixed vanes.



(c) Station 5, turbine inlet. Passage height,  $6\frac{3}{4}$  inches; location,  $1\frac{3}{4}$  inches upstream of leading edge of first-stage turbine-nozzle diaphragm.



(d) Station 6, turbine outlet. Passage height,  $5\frac{5}{8}$  inches; location,  $3\frac{3}{8}$  inches downstream of trailing edge of turbine rotor.

Figure 7. - Location of instrumentation (view looking downstream).

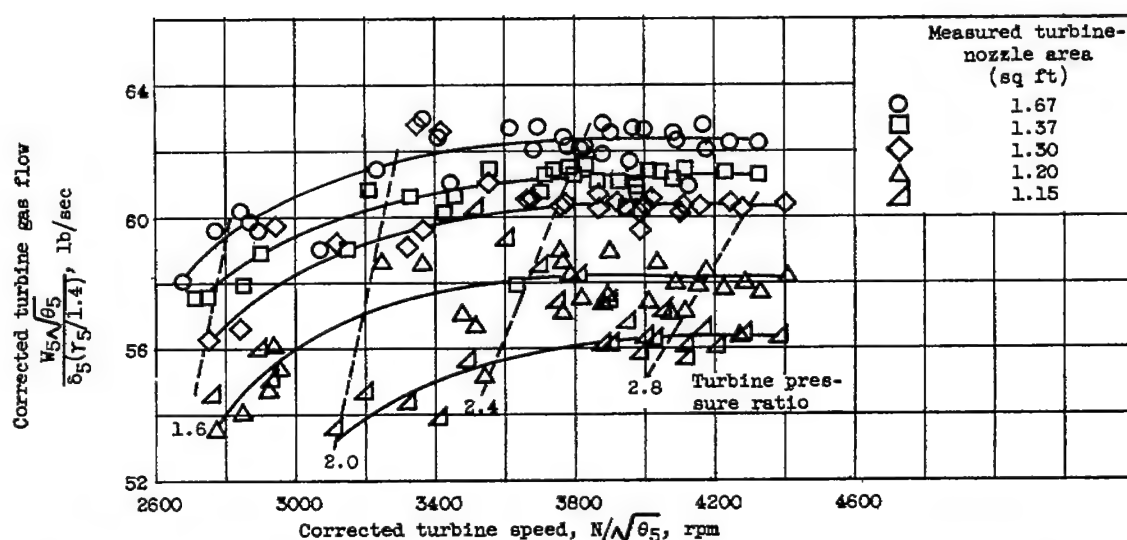


Figure 8. - Effect of turbine-nozzle area and corrected turbine speed on corrected turbine gas flow. Altitude, 30,000 feet; flight Mach number, 0.62.

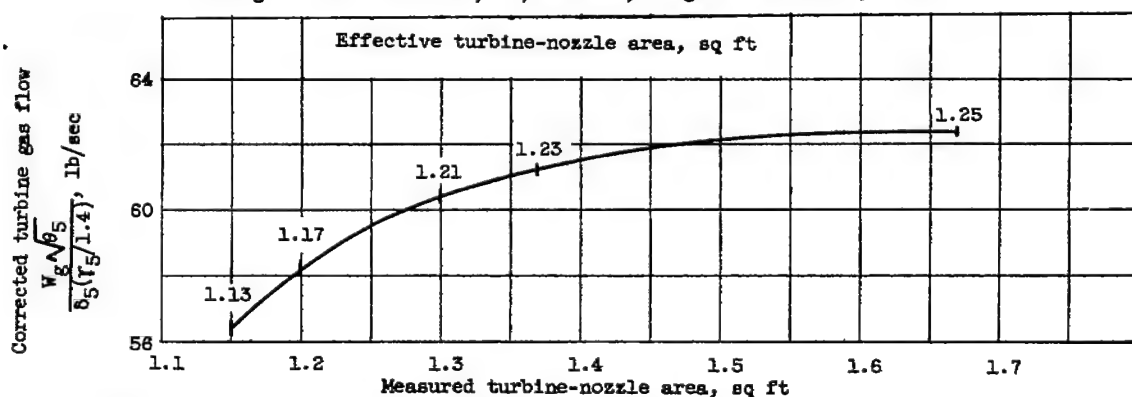


Figure 9. - Variation of maximum corrected turbine gas flow or effective turbine-nozzle area with measured turbine-nozzle area. Altitude 30,000 feet; flight Mach number, 0.62.

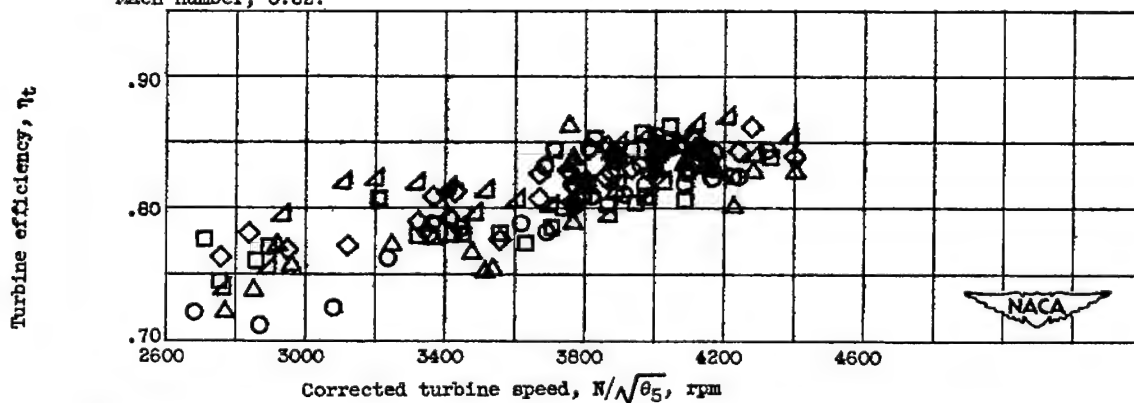
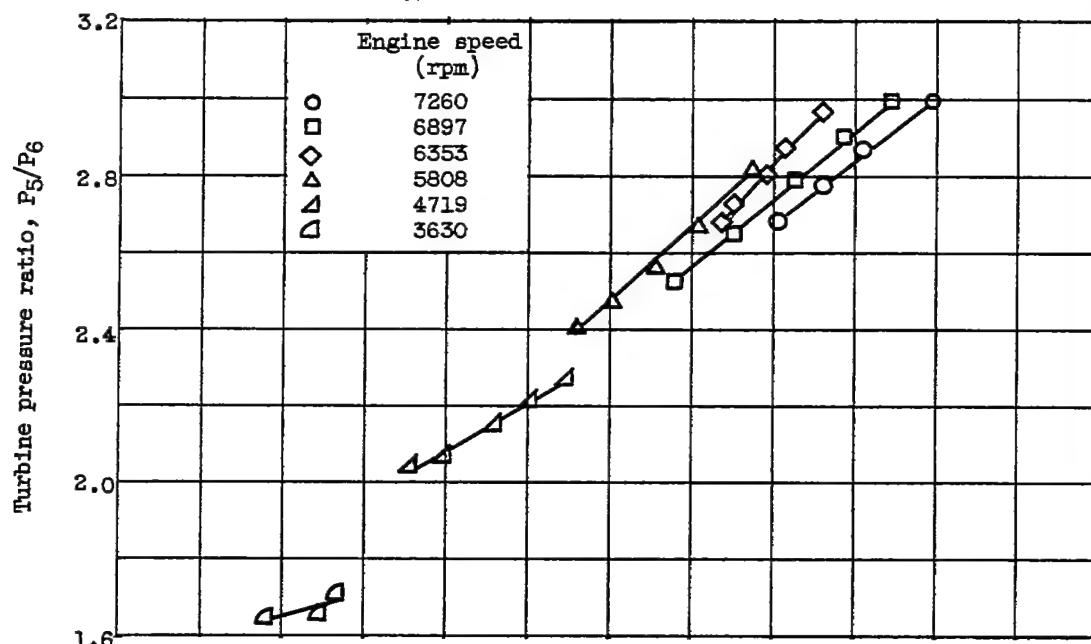
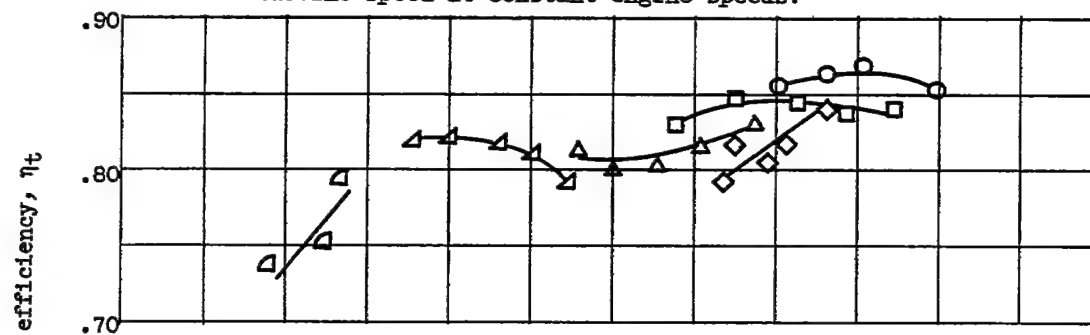


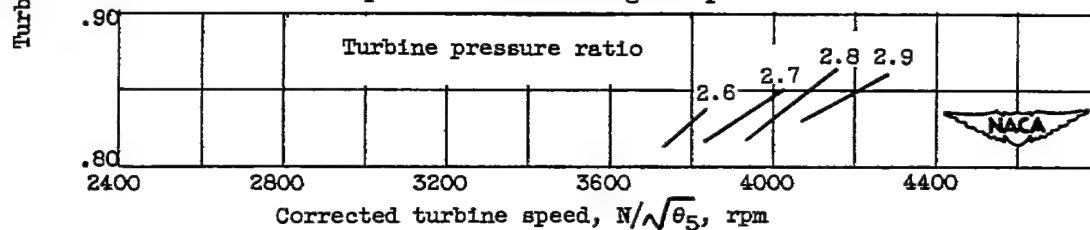
Figure 10. - Effect of turbine-nozzle area and corrected turbine speed on turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62.



(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.

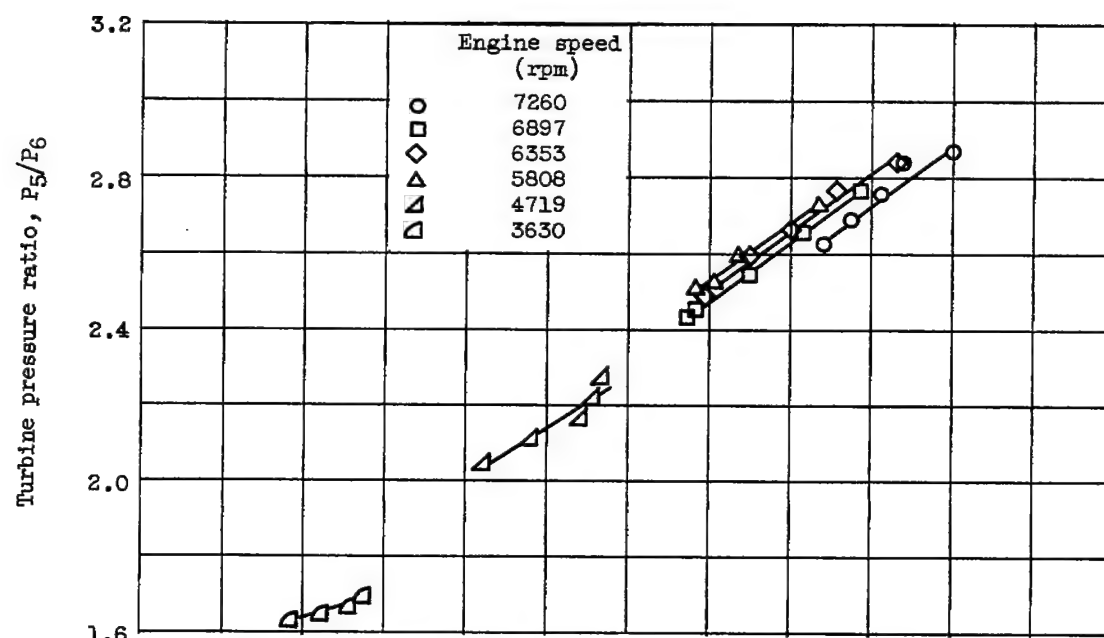


(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.

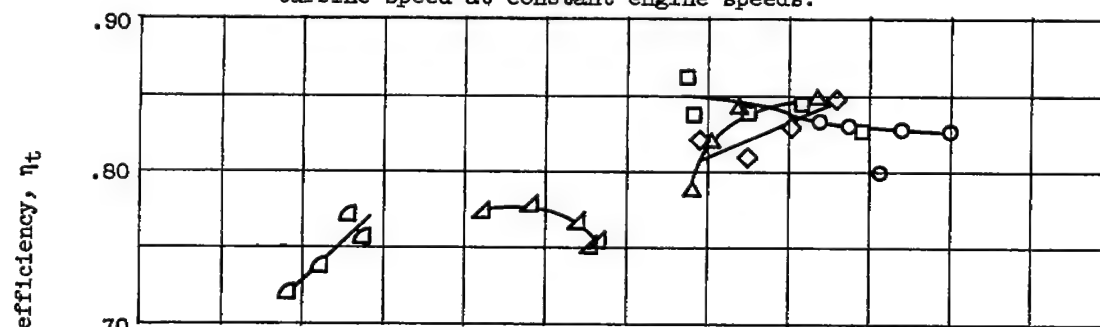


(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

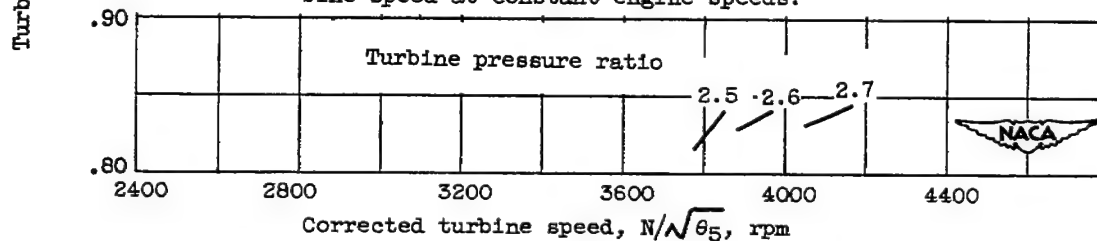
Figure 11. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.15 square feet.



(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.



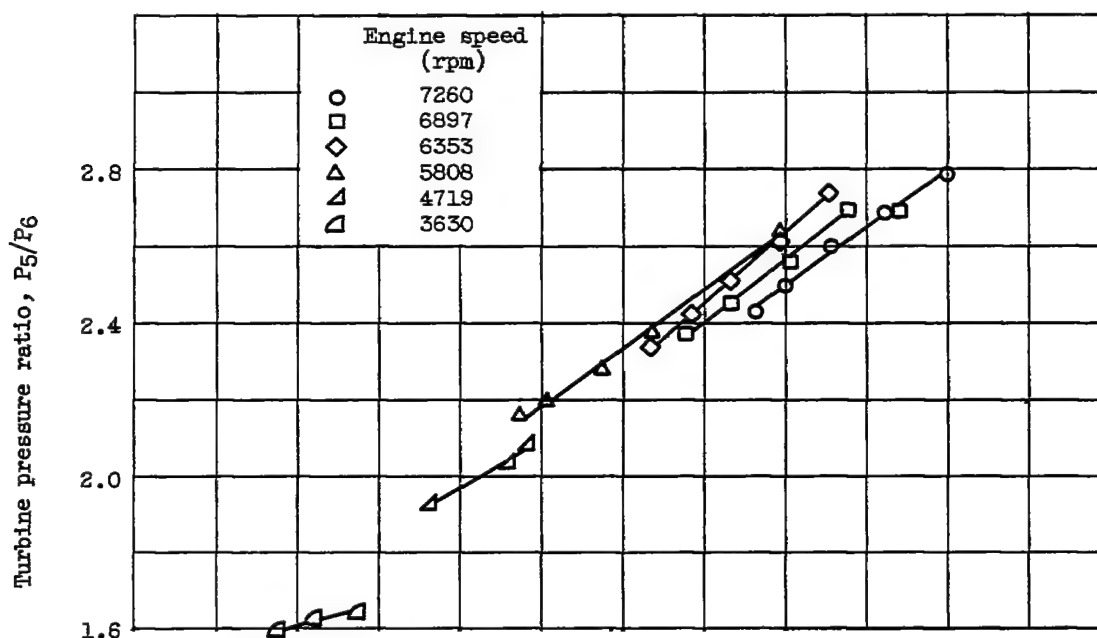
(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.



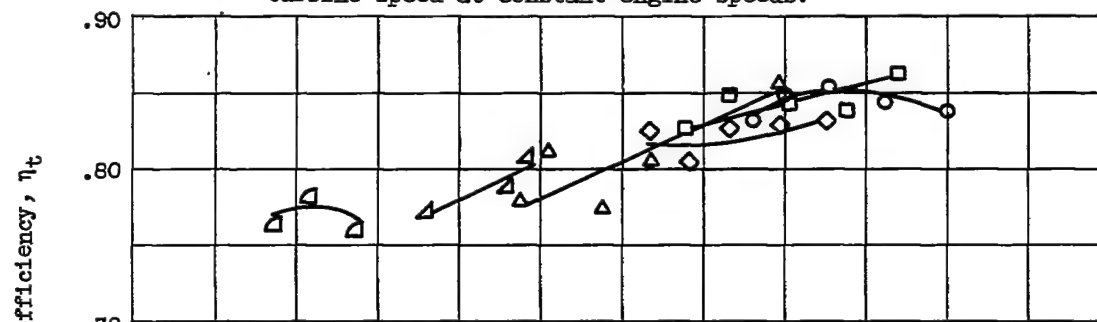
(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

Figure 12. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.20 square feet.

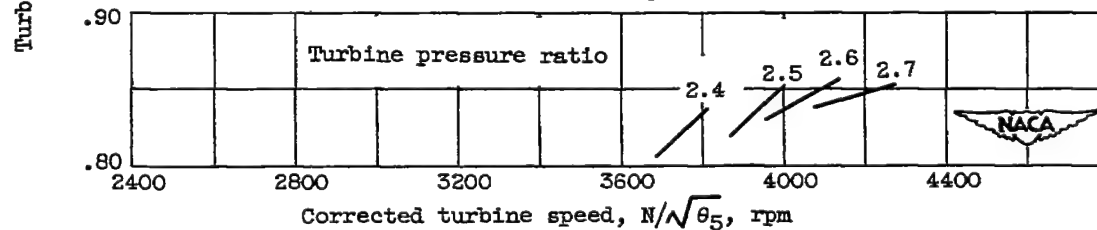




(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.

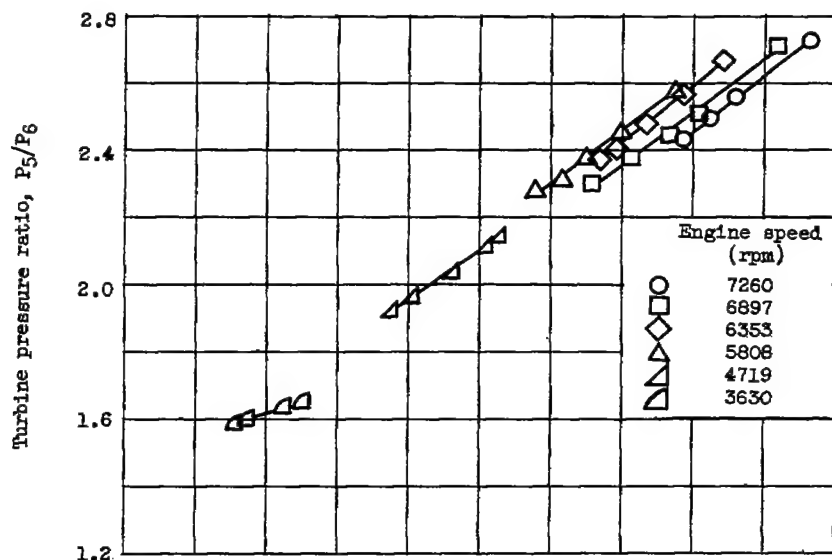


(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.

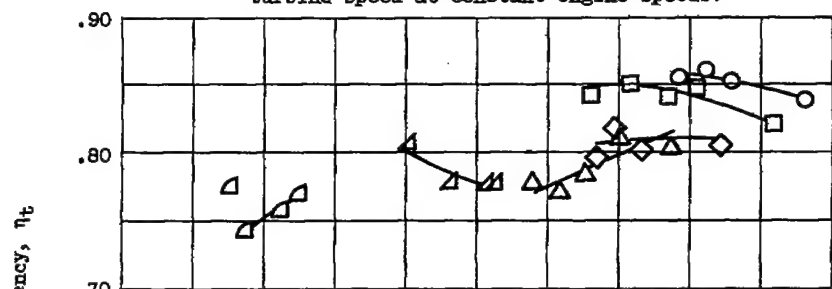


(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

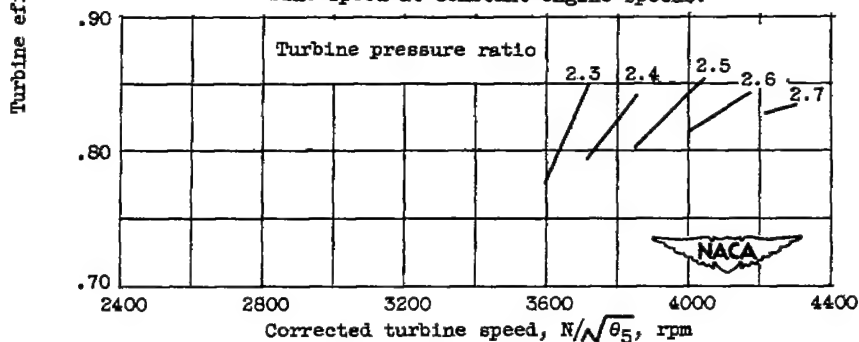
Figure 13. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.30 square feet.



(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.

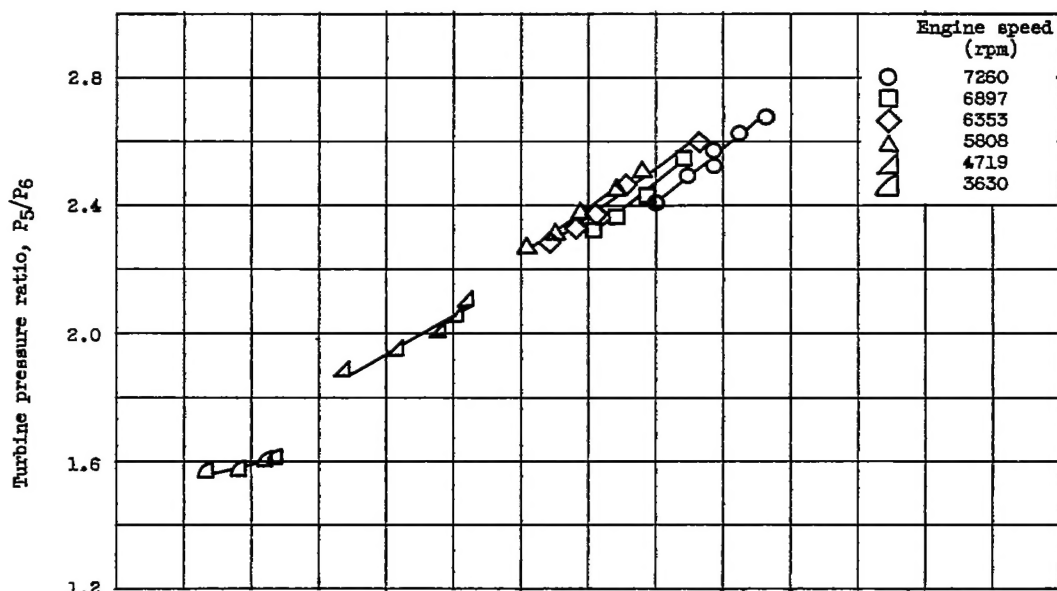


(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.

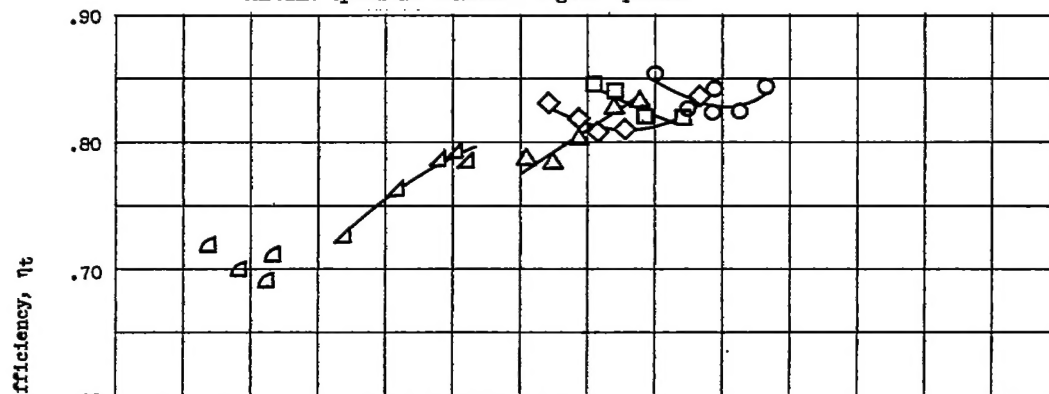


(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

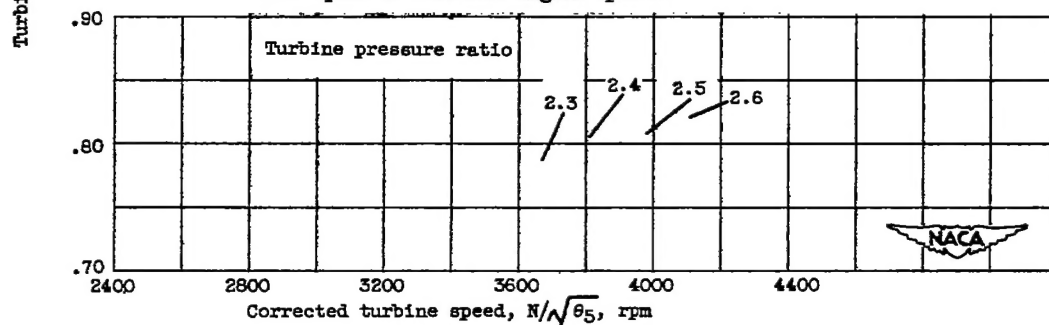
Figure 14. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.37 square feet.



(a) Variation of turbine pressure ratio with corrected turbine speed at constant engine speeds.



(b) Variation of turbine efficiency with corrected turbine speed at constant engine speeds.



(c) Cross plots showing variation of turbine efficiency with corrected turbine speed at constant values of turbine pressure ratio.

Figure 15. - Effect of various parameters on turbine pressure ratio and turbine efficiency. Altitude, 30,000 feet; flight Mach number, 0.62; turbine nozzle area, 1.67 square feet.

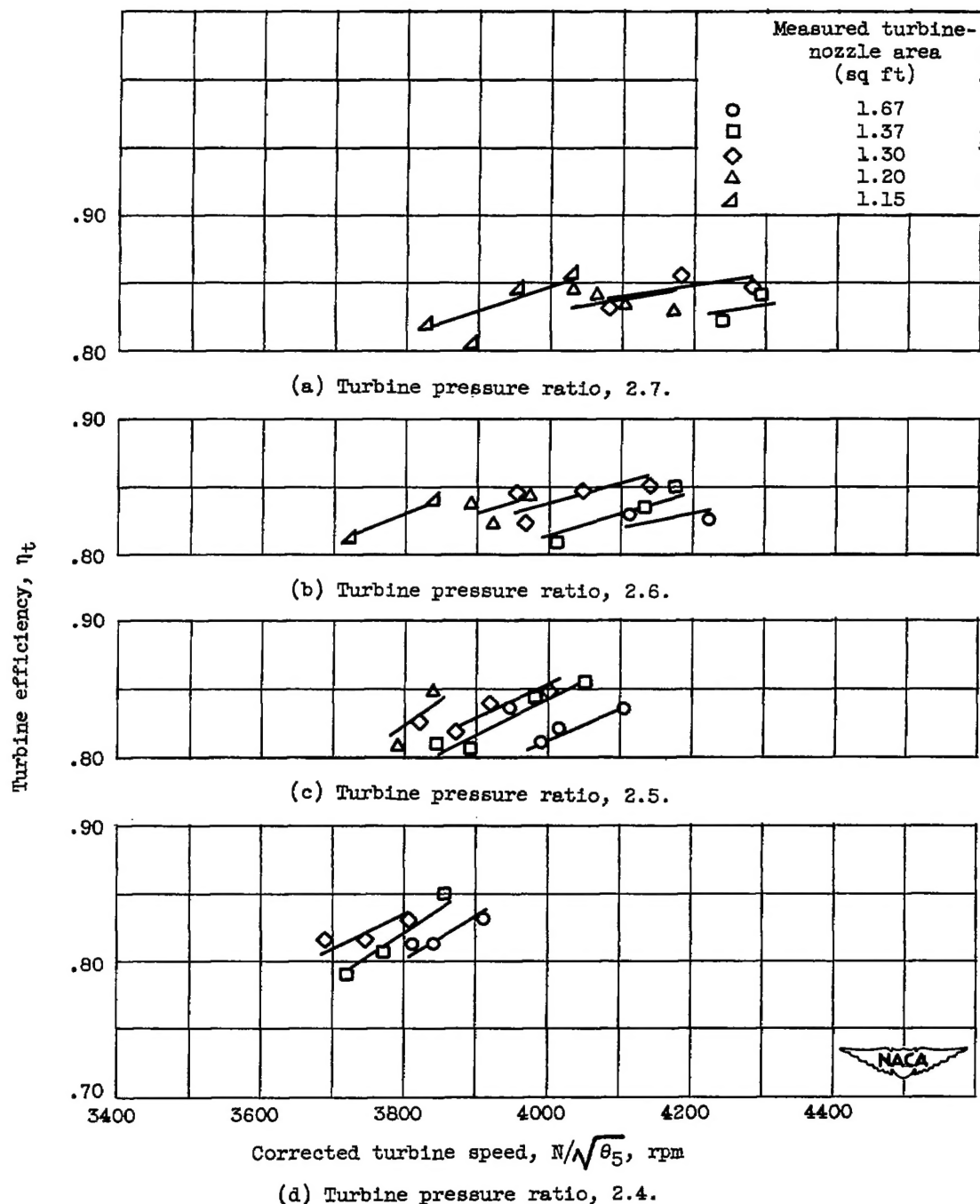


Figure 16. - Effect of turbine-nozzle area and corrected turbine speed on turbine efficiency at constant values of turbine pressure ratio. Altitude, 30,000 feet; flight Mach number, 0.62.

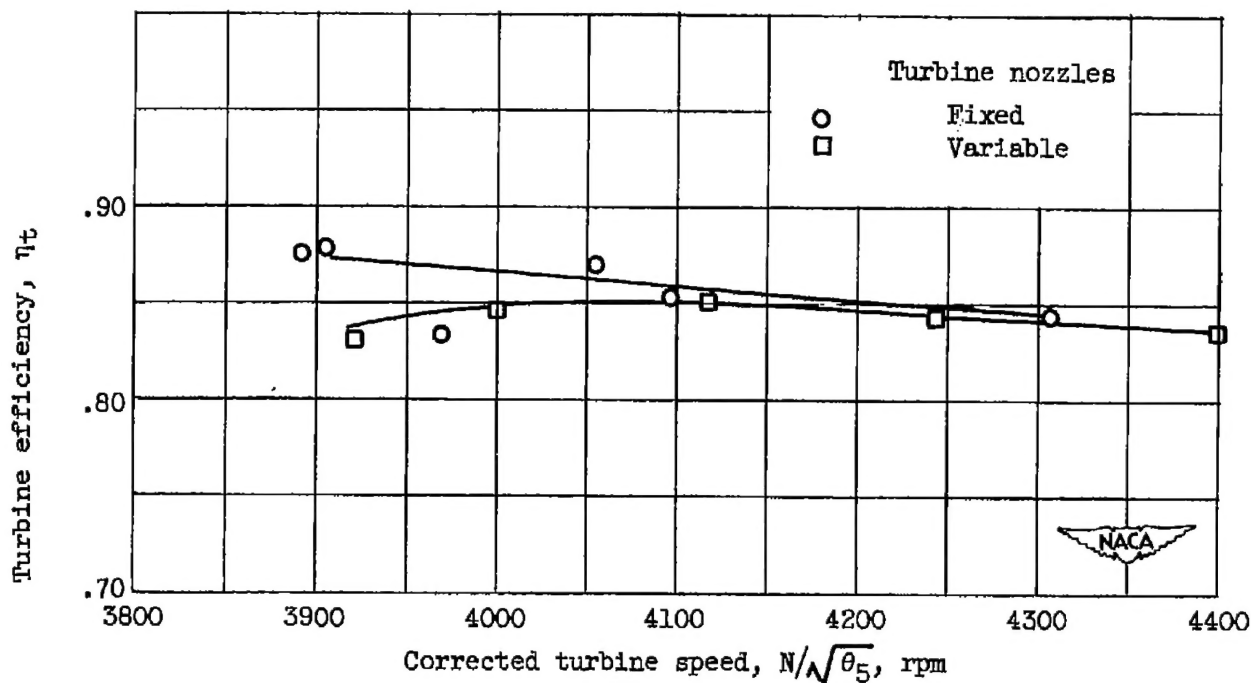


Figure 17. - Comparison of efficiencies obtained with fixed turbine nozzles and with variable-area turbine nozzles for an actual turbine-nozzle area of 1.30 square feet. Altitude, 30,000 feet; flight Mach number, 0.62; engine speed, 7260 rpm.

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